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UNIVERSITÉ DE MONTRÉAL

CONTRÔLE DES OLIGOCHÈTES DANS LES USINES DE TRAITEMENT D'EAU POTABLE

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Ce mémoire intitulé:

CONTRÔLE DES OLIGOCHÈTES DANS LES USINES DE TRAITEMENT D'EAU POTABLE

Présenté par: BEAUDET Jean-François

En vue de l'obtention du grade de: Maîtrise ès sciences appliquées

a été dûment accepté par le jury d'examen constitué de:

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Mme PRÉVOST Michèle, Ph. D., membre et directrice de recherche

M. LAFRANCE Pierre, M. Ing., membre

DÉDIDACE

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SOMMAIRE

L'ensemble des travaux de recherche présentés dans ce mémoire ont été réalisés à l'usine de production d'eau potable Sainte-Rose (Ville de Laval, Québec, Canada) entre 1995 et 1998.

L'usine de production d'eau potable Sainte-Rose (capacité nominale de 110 000 m^3/d) est composée de la filière de traitement suivante: dégrillage primaire, coagulation-floculation-décantation dynamique par le procédé super-pulsator, filtration sur sable et anthracite (10 m/h), ozonation (résiduel de 0,4 mg O_3/l après 10 minutes) , filtration sur charbon actif biologique (CAB) (10 m/h), désinfection par le bioxyde de chlore et ajustement de pH entre 7,3 et 7,6. Elle est alimentée à partir des eaux brutes de la rivière des Mille-Iles.

Un des objectifs de cette recherche était dans un premier temps de développer des méthodes de mesure permettant d'évaluer la population d'oligochètes dans les usines de traitement d'eau potable en vue d'en contrôler la présence. Dans cette perspective, deux méthodes de mesure, l'une pour un milieu filtrant, l'autre pour l'eau, ont d'abord été développées dans le but d'évaluer les populations d'oligochètes respectifs dans chaque cas. La première méthode, simple et rapide, permet d'évaluer la population d'oligochètes dans les filtres CAB. La procédure de laboratoire consiste à prélever des échantillons de matériaux filtrants provenant des filtres pour être ensuite analysés. Les oligochètes sont ensuite dénombrés à partir des échantillons prélevés et les densités d'oligochètes sont alors déterminées. Les densités d'oligochètes mesurées dans les filtres CAB de l'usine Sainte-Rose de Laval ont varié entre 0 naïdide/ml (limite de détection de la méthode) en eaux froides jusqu'à 25 naïdides/ml en eaux chaudes. Cette méthode pourrait s'utiliser pour dénombrer d'autres types de macro-organismes tels que les chironomides, etc.. La seconde méthode fait appel à une colonne de filtration qui concentrent les oligochètes présents dans l'eau. Les concentrations d'oligochètes sont ensuite estimées à partir du

nombre d'oligochètes retenus dans la colonne. Les concentrations d'oligochètes les plus importantes ont été mesurées à l'effluent des filtres CAB en période de filtration à des concentrations allant jusqu'à 20 naïdides/m^3 .

Suite au développement des méthodes, un suivi des oligochètes dans les filtres CAB a alors été effectué dans le but de déterminer les périodes durant lesquelles les oligochètes étaient présents en usine. Durant près d'un an, les profils de densités d'oligochètes dans les filtres ont été dressés de façon régulière. Il ressort que les oligochètes ne sont pas détectables dans les filtres CAB en période d'eaux froides, entre les mois de janvier et mai. A partir de juin, la colonisation des filtres CAB par les oligochètes s'accélère rapidement pour atteindre la population d'équilibre dès le début du mois de juillet. Ces densités d'oligochètes mesurées demeurent élevées jusqu'à la fin du mois de septembre, où alors les densités d'oligochètes recommencent à diminuer. Les variations climatiques pourraient toutefois faire varier les périodes durant lesquelles les oligochètes sont présents en usine.

Différentes techniques de contrôle des oligochètes ont été analysées. Ces techniques ont porté dans un premier temps sur l'impact des techniques de lavage sur les populations d'oligochètes dans les filtres CAB. Trois techniques de lavages de filtres ont été étudiées : rinçage à contre-courant à l'eau seulement, brassage à l'air suivi d'un rinçage à l'eau à contre-courant, brassage à l'air suivi d'un rinçage à l'eau à débit variable. Ces essais ont permis de constater que les lavages avaient peu d'effet sur la population d'oligochètes, selon la méthode de mesure utilisée.

Une dernière technique de lavage a aussi été évaluée. Elle consistait à effectuer d'abord un arrêt de filtration de six heures et ensuite à effectuer un rinçage à l'eau à faible débit, un brassage à l'air, suivi d'un rinçage à l'eau à débit moyen. Cette technique a permis de constater que la population d'oligochètes était substantiellement réduite à la suite de cette

technique de lavage, les densités d'oligochètes en surface des filtres passant de 11 naïdides/ml à près de 1 naïdides/ml. L'impact de la technique sur les densités d'oligochètes était perceptible sur deux cycles de filtration de 96 heures. Durant cette même période, les concentrations d'oligochètes à l'effluent des filtres CAB ont été réduites substantiellement à moins de 0,1 naïdide/m^3, à l'exception des 20 premières minutes suivant le premier lavage précédé d'un arrêt de filtration où la concentration d'oligochètes a atteint 160 naïdides/m^3. L'utilisation de cette technique permet de maintenir les capacités d'enlèvement biologique suite à l'arrêt de filtration et au lavage. Les capacités d'enlèvement biologique du carbone organique dissous et de l'azote ammoniacal avant et après l'application de la technique de lavage sont conservées.

ABSTRACT

These research works presented in this thesis was carried out at the Ste. Rose drinking water treatment plant (Laval, Québec, Canada) between 1995 and 1998.

The Ste. Rose drinking water production plant (nominal capacity 110,000 m^3/d) is composed of the following treatment steps: screening, dynamic coagulation-flocculation-settling using the super-pulsator process, sand and anthracite filtration (10 m/h), ozonation (residual of 0.4 mg O_3/l after 10 minutes), biological activated carbon (BAC) filtration, chlorine dioxide disinfection and pH adjustment to 7.3-7.6. The plant is fed by raw waters from the Mille Iles River.

One of the objectives of this research was first of all to develop measurement methods for evaluating the oligochaete populations in drinking water treatment plants with a view to controlling them. In order to achieve this, two measurement methods, one for use in filter media and the other for use in water, were developed for the purpose of determining the levels of oligochaete populations present in each case. The first, a simple and quick method, evaluates the population of oligochaetes in BAC filters. The laboratory procedure consists in taking samples from the filters. Then, the oligochaetes contained in samples are counted and the oligochaete densities are determined. The oligochaete densities measured in the BAC filters at the Ste. Rose plant varied between 0 naidid/ml (detection limit of the method) in cold waters to 25 naidids/ml in warm waters. This method could also be used to count other types of macro-organisms, such as chironomids, etc. The second method consists in measuring the concentrations of oligochaetes in the water using a filtration column. The greatest concentrations were measured in the effluent of the BAC filters during the filtration period, up to a maximum of 20 naidids/m^3.

Once methods have been developed, the oligochaetes in BAC filters were monitored in order to determine the periods during which oligochaetes are present in treatment plants. For nearly a year, oligochaete density profiles were created on a regular basis. It appears that oligochaetes are not detectable in BAC filters during periods when the waters are cold, between January and May. From June, the colonization of BAC filters by oligochaetes accelerates rapidly, until the population reaches equilibrium at the beginning of July. These densities remain high up to the end of September, when they begin to drop. Climatic conditions could, however, vary the periods during which oligochaetes are present in treatment plants.

Various oligochaete control techniques were analyzed. The first of these had to do with the impact of backwashing techniques on oligochaete populations in BAC filters. Three filter backwashing techniques were studied: backwashing with water only, an air scour followed by backwashing with water and an air scour following by backwashing with water at a variable flow rate. Results obtained from these works showed that these backwashing techniques had little effect on oligochaete populations, according to the measurement method used.

Another backwashing technique was also evaluated, which consisted of a shutdown of filtration for six hours and backwashing the filter with water at a low flow rate, and an air scour followed by backwashing with water at a medium flow rate. As a result of applying this backwashing technique, the oligochaete population in BAC filteres can be substantially reduced by this technique, the oligochaete densities at the surface of the filters dropping from 11 naidids/ml to nearly 1 naidids/ml. The impact of the technique on the oligochaete densities was perceptible after two filtration cycles of 96 hours. During the same period, the concentrations of oligochaetes in the effluent of the BAC filters was substantially reduce, to fewer than 0.1 naidid/m^3, except following the first backwashing preceded by a filter shutdown, when the concentration of oligochaetes

reached 160 naidids/m^3. The use of this backwashing technique can maintain performances of biological performance after a filter shutdown following by backwashing. The dissolved organic carbon and ammonia removals can be maintained.

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COD	carbone organique dissous
CODB	carbone organique dissous biodégradable
CAB	charbon actif biologique
DPB	Disinfection by-product
SPAF	sous-produits d'arrêt de filtration
SPD	sous-produits de désinfection
SA	sable et anthracite
DOC	dissolved organic carbon
BDOC	Biological dissolved organic carbon
TOC	Total organic carbon

CHAPITRE 1: INTRODUCTION

1.1 MISE EN CONTEXTE

Le resserrement des normes environnementales au Canada et aux États-Unis en matière d'eau potable incite les producteurs d'eau, en majorité des villes et des municipalités, à se doter de nouvelles technologies de traitement plus ou moins complexes et sophistiquées selon la qualité de l'eau brute à traiter. L'utilisation de ces technologies vise d'une part à réduire les risques de recroissance bactérienne dans les réseaux de distribution d'eau potable et d'autre part, à réduire le potentiel de formation de sous-produits de désinfection (SPD), dans le but ultime d'améliorer les qualités physico-chimiques de l'eau potable et de réduire les risques d'infection dans les populations desservies.

Des procédés variés ont été développés au cours des dernières années pour améliorer la qualité de l'eau potable. Parmi ces procédés, la filtration sur charbon actif biologique (CAB) précédée de l'ozonation a connu un essor considérable au cours des deux dernières décennies, principalement en Europe et au Québec. La synergie existant entre ces deux procédés contribue à assurer à l'eau traitée une stabilité microbiologique accrue en réseau en plus de réduire le potentiel de formation des SPD (Bablon et al. 1986; Ciparrone et al. 1997; Prévost 1992 ; Servais et al. 1986).

L'ozone est un puissant oxydant ayant la capacité d'oxyder la matière organique dissoute difficilement biodégradable en du carbone organique dissous biodégradable (CODB) (Doré 1989; Gilbert et Zinecker 1980; Servais 1991; van der Kooji et Hijnen 1984). Pour éviter que le carbone organique formé favorise la recroissance bactérienne et la formation de SPD à l'étape de désinfection, une filtration sur CAB est placée en aval de l'étape d'ozonation. En effet, l'utilisation de charbon actif, et plus particulièrement de charbon actif de type macro-poreux, fournit un nombre important de sites pour le développement

d'une flore bactérienne permettant l'enlèvement du CODB disponible formé durant l'étape d'ozonation (Bablon et al. 1991; Prévost 1992). L'abattement du CODB permet alors de réduire les risques de recroissance bactérienne en réseau et de diminuer la quantité de SPDs formés lors de la post-chloration.

L'usine de production Sainte-Rose (Ville de Laval, Québec, Canada) inaugurée en 1984 fut la première usine construite en Amérique du Nord à faire appel à une filtration biologique sur CAB en deuxième étage précédé d'une étape d'ozonation afin de limiter les risques de recroissance bactérienne et la présence de SPD en réseau. Deux types de filtration sont présents: une filtration sur sable et anthracite (SA) en premier étage de filtration, qui permet d'abord d'enlever les matières en suspension dont la matière organique particulaire, et une filtration sur CAB en deuxième étage de filtration, qui contribue à enlever la matière organique dissoute biodégradable. Plusieurs études réalisées à l'usine Sainte-Rose ont d'ailleurs montré des avantages de l'utilisation d'une filtration biologique précédée d'une étape d'ozonation sur la qualité de l'eau traitée (Prévost 1991).

En dépit des avantages que cette technologie de traitement de l'eau potable procure, certains problèmes liés à son utilisation peuvent se manifester en usine. En effet, les bactéries sont à la base d'une chaîne trophique pouvant mener au développement d'organismes supérieurs dans des conditions environnementales favorables: température de l'eau élevée, présence de nutriments (COD, azote, phosphore, etc.), absence de prédateurs, etc.. Des cyclopes, des nématodes, des chironomides ou encore des oligochètes peuvent alors faire leur apparition dans les filtres biologiques et les coloniser.

A l'usine de production d'eau potable Sainte-Rose, le développement d'une chaîne trophique importante est observé durant la saison estivale: les oligochètes, les chironomides et les nématodes colonisent alors les filtres CAB à divers degrés. Or, la

présence de ces organismes n'est pas désirable en usine en raison des risques potentiels de leur passage dans les réseaux de distribution et jusqu'au robinet des consommateurs.

Les organismes supérieurs les plus répandus dans les filtres CAB de l'usine de production d'eau potable Sainte-Rose sont de la classe des oligochètes de l'embranchement des annélides. Cette classe est divisée en plusieurs familles, à savoir les Naïdides, les Tubificides, les Enchytraeides, les Lumbriculides, les Haplotaxides, les Opistocystides et les Aeolosomatides. La classe d'oligochètes identifiée comme peuplant les filtres CAB a été celle des naïdides. Cette identification a été rendue possible par la présence d'yeux et d'un prostomium appelé proboscys (Brinkhurst 1986; Brinkhurst 1997; Brinkhurst et Gelder 1991). Les naïdides sont des vers translucides qui mesurent habituellement moins de deux centimètres de long et qui vivent dans les étangs, les endroits tranquilles des rivières et les baies protégées des lacs. Ils se nourrissent de micro-organismes présents au fond des zones inondées et se multiplient rapidement dans des milieux pollués par la matière organique. Les naïdides peuvent se reproduire par reproduction sexuée ou asexuée; la reproduction sexuée conduit à la formation de cocons tandis que la reproduction asexuée s'effectue par fragmentation ou par segmentation d'un individu en deux individus distincts.

En vue de limiter la prolifération d'organismes supérieurs dans les filtres biologiques et en vue d'éviter leur présence à l'eau filtrée, le développement de certaines techniques de contrôle peut s'avérer essentiel. Cependant, ces techniques doivent permettre de maintenir les capacités d'enlèvement biologique des filtres en terme de réduction du COD, du CODB et du potentiel de formation des SPDs.

Jusqu'à présent, la technique utilisée à l'usine Sainte-Rose pour limiter la prolifération des naïdides dans les filtres CAB consistait à augmenter la fréquence des lavages des filtres de manière à limiter les populations dans les filtres (Arcouette 1995). La

fréquence des lavages était alors dictée par la présence plus ou moins importante de naïdides dans les eaux de lavage. Cependant, cette technique ne permettait pas d'évaluer précisément la population de naïdides dans les filtres. Le développement de méthodes de mesure plus adaptées a donc été envisagé afin d'évaluer avec plus de précision dans un premier temps les densités de naïdides dans les filtres CAB et dans un second temps, les concentrations de naïdides à l'effluent des filtres CAB.

En raison du peu d'informations disponibles à ce jour sur le contrôle des oligochètes en usine, des recherches ont été entreprises dans le but de déterminer les niveaux de populations d'oligochètes en usine particulièrement dans les filtres CAB, et de valider des techniques de contrôle pour en limiter leur présence.

L'objectif principal de cette étude est de proposer une stratégie de contrôle des populations d'oligochètes dans les filtres biologiques en deuxième étage de filtration sans altérer les capacités d'enlèvement biologique des filtres CAB.

Ce mémoire discute des résultats obtenus lors des recherches effectuées principalement sur les filtres CAB de l'usine de production d'eau potable Sainte-Rose (Ville de Laval, Québec, Canada).

1.2 OBJECTIFS DE L'ÉTUDE

Les objectifs poursuivis dans le cadre de ce projet de recherche sont les suivants :

1. développer des méthodes de mesure simples, efficaces et rapides permettant d'estimer la population d'oligochètes dans les usines de traitement d'eau potable;
2. déterminer les périodes durant lesquelles les oligochètes sont présents en usine;
3. évaluer différentes techniques de contrôle des populations d'oligochètes dans les filtres CAB;
4. proposer une technique de contrôle des populations d'oligochètes dans les filtres CAB;
5. proposer une stratégie de prévention du développement des populations d'oligochètes dans les filtres CAB en fonction de l'année.

Ce mémoire de maîtrise présente les résultats de cette étude qui s'est déroulée entre juin 1995 et mai 1997.

CHAPITRE 2: MÉTHODES DE MESURE POUR L'ESTIMATION DES POPULATIONS D'OLIGOCHÈTES DANS LES USINES DE TRAITEMENT D'EAU POTABLE

2.1 INTRODUCTION

Étant donné le manque de méthodes pour déterminer les niveaux de populations d'organismes supérieurs dans les filtres, la première partie de ce projet de recherche consistait à développer des outils d'estimation des populations d'oligochètes dans les usines de traitement d'eau potable.

Ce premier chapitre, présenté sous forme d'article à la section 2.2, a pour but de décrire les méthodes de mesure qui ont été développées pour estimer les populations d'oligochètes dans des échantillons de milieu filtrant et dans des échantillons d'eau filtrée en continu. Ces méthodes sont dérivées des méthodes utilisées dans le domaine de la limnologie.

Dans un premier temps, une méthode d'estimation des densités d'oligochètes dans des échantillons de matériau filtrant a été développée et est proposée pour évaluer la population d'oligochètes dans les filtres à CAB. Elle consiste à extraire des échantillons de matériau filtrant à l'aide d'un carotteur muni d'ouvertures pour prélever des échantillons à différentes profondeurs. Ces échantillons sont ensuite analysés pour y dénombrer le nombre d'oligochètes présents. Des analyses statistiques ont été effectuées à l'aide du programme Statistica 5.1, version 97, pour Windows 95 de Statsoft Inc. afin de déterminer la précision de la méthode de mesure.

Dans un second temps, une méthode d'estimation des densités d'oligochètes dans des échantillons d'eau filtrée en continu est proposée. Cette méthode fait appel à une colonne

de filtration qui concentre sur un tamis les oligochètes présents dans de l'eau provenant de différents points d'échantillonnage de la filière de traitement. Les analyses statistiques ont été réalisées à l'aide du programme Statistica 5.1, version 97, pour Windows 95 de Statsoft Inc..

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2.2 SIMPLE METHODS FOR EVALUATING THE POPULATION OF OLIGOCHAETES IN DRINKING WATER TREATMENT PLANTS

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ABSTRACT

This paper focuses on the development of simple methods to estimate the population of members of the naidid family from the class of oligochaetes in biological activated carbon (BAC) filters and in water. Research was carried out at the Ste. Rose Drinking Water Treatment Plant from August 1995 to September 1996. Two methods derived from limnology applications and adapted for the field of drinking water are described and were tested. The first method permits the enumeration of oligochaetes in a sample of filter media. Statistical analysis of the data have shown that samples taken at the surface of the filter media at depths between 0 and 200 mm were statistically different from those taken at deeper levels. Experimental results showed that samples taken at the surface of the filter media represent the maximum oligochaete densities measured in BAC filters. Deeper within the BAC filter, oligochaete densities approached the detection limit. Typical oligochaete densities encountered ranged from the limit of detection (1 naidid/4 ml) in cold water (1°C) to 25 naidids/ml in warm water (25°C) in the top portion of the filter. In the second method, a filtration column is used to concentrate oligochaetes present in the effluent of BAC filters. In this study, the oligochaete concentrations in the BAC filter effluent varied between the limit of detection and 20 naidids/m^3. The filtration column method may be used at different steps in the process in order to determine the occurrence of oligochaetes in the treatment chain. Both methods tested could be used for the enumeration of other types of invertebrates such as chironomids.

INTRODUCTION

The strengthening of drinking water quality standards is prompting an increasing number of water utilities to consider using a biological filtration step in their drinking water treatment plants. Numerous studies have suggested that filtration on biological activated carbon (BAC) preceded by ozonation can respond to the growing need to improve the physico-chemical and biological qualities of drinking water (Bablon et al. 1986; Prévost et al. 1989; Servais et al. 1987; van der Kooij et Hijnen 1984).

The use of biological filtration in drinking water treatment may bring about a need to modify filter operation. The criteria for backwashing a conventional filter are usually based on the turbidity of the filter's effluent, on the filter's headlosses or on the maximal duration of filtration (AWWA 1991). With the addition of a biological filtration step, higher forms of organisms such as invertebrates may colonize and proliferate in biological filters due to higher levels of biomass fixed on media grains (Beaudet et al. 1996; Prévost et al. 1990; Thibault 1994). This proliferation of invertebrates can occur in any filter media but by favouring the growth of fixed biomass, the potential for invertebrate development is increased. Rook (1970) reported that consumers have discovered in the tap water macro-invertebrates that had grown in the sand filters of the Rotterdam water supply in the Netherlands. Hence, a fourth criterion for backwashing could be considered for all types of filters: controlling the densities of invertebrates in the filters and their passage to the filtered water. Invertebrate control in treatment plants is an important goal since some studies have shown that a wide trophic chain of micro-organisms existing in distribution systems could possibly support the growth of larger macro-organisms (Amblard et al. 1996). Moreover, invertebrates such as some species of oligochaetes can support the growth of bacteria on their surface or in their gut (Chatarpaul et al. 1980; Harper et al. 1981).

To meet this latter criterion for backwashing, a first indirect technique for estimating the population of invertebrates in BAC filters consisting in monitoring the number of the oligochaetes in backwash water during a filter backwash was proposed by Arcouette (1995). An increase in the oligochaete densities in backwash water triggered a higher frequency of backwashing, the objective of which was to prevent the proliferation of these organisms in the BAC filter and their passage to the filtered water. However, the population of invertebrates present in filters could not be estimated with this method, thereby limiting the operator's ability to evaluate the impact of the increase of backwashing frequency.

The new methods proposed in this article are derived from limnology applications and offer a simple and reliable way to evaluate the populations of invertebrates in drinking water treatment plants. Various collection techniques in which dip nets or core tubes are used to identify invertebrates present in sediments are used in limnology. These samplers have been adapted for use in drinking water treatment plants, as biological filters contain populations of invertebrates and bacteria similar to those found in sediments at the bottom of lakes.

STUDY OBJECTIVES

The objective of this study was to devise simple methods for evaluating the population of oligochaetes in drinking water treatment plants. Two methods were developed: the first one to estimate the oligochaete population in filter media samples, and the second to evaluate the oligochaete population in water samples. Statistical analyses were performed mainly on the first method in order to verify its reproducibility and to identify sources of variation.

MATERIAL AND METHODS

Ste. Rose Drinking Water Treatment Plant

Methods were devised at the Ste. Rose drinking water treatment plant (City of Laval, Québec, Canada). The nominal capacity of the plant is 110,000 m^3/d. The Mille Iles River, which has a high organic load (4-10 mg COD/l) and a low alkalinity 30 mg $CaCO_3/l$, supplies water to the plant. The river receives some untreated sewage, especially from combined sewer overflow. A schematic flow diagram of the Ste. Rose plant is presented in Figure 2.1. The treatment processes include screening, dynamic settling, filtration on sand and anthracite (10-m/h superficial velocity), ozonation (0.4 mg O_3/l after 10 minutes), filtration on biological activated carbon (BAC) (10-m/h superficial velocity), post-disinfection with chlorine dioxide and final pH adjustment to 7.3-7.6.

Sampling

Media samples were taken from the same BAC filter during the period from August 1995 to September 1996 and water samples were collected at the effluent of BAC filters for enumeration of oligochaetes in June and July 1996. Figure 2.2 shows the filter media sampling depth symbolized by FD. Total filter depth was estimated to be 1.82 m. The frequency of BAC filter backwashing ranged from 48 h in warm water to 168 h in cold water over the sampling period.

Oligochaetes enumerated at the plant

The dominant type of macro-invertebrates enumerated in media samples and in water samples belonged to the naidid family from the class of oligochaetes. A naidid observed by means of bright-field microscopy is shown in Figure 2.3. The presence of simple eyes associated with the proboscis on is specimen permits us to identify the oligochaete as being from the naidid family (Brinkhurst 1986; Brinkhurst 1997; Brinkhurst et Gelder 1991).

Description of the methods

Two methods were developed and adapted from limnology to estimate the population of oligochaetes in filter media and in water. These methods are presented in the following sections.

Enumeration of oligochaetes in filter media samples

In this first method, samples are collected at different depths using a core tube inserted in the filter media. The enumeration of naidids present in the media samples is possible following the addition of chlorinated water to these samples. Oxidized by chlorine, naidids become inert and white, and easily visible within a few minutes. The contrast between the oxidized oligochaetes and the media grains facilitates their enumeration.

The equipment needed for the method is composed of a core tube or a surface sampler, a Darkfield Colony Québec Counter or a high-powered magnifying lens, cross-ruled Petri dishes and a suitable lighting. A 5 % commercial bleach (Lavo Ltée, Canada) mixed with tap water was used to oxidize the oligochaetes in the media samples.

The use of a Darkfield Colony Québec Counter or a high-powered magnifying lens makes the enumeration process easier by enlarging apparent size of the oligochaetes. The Québec Counter's surface should be placed in a horizontal position because the Petri dish contains media grains floating in water (Figure 2.4). Furthermore, since the lighting provided by this instrument is inadequate for counting oligochaetes, an external lighting source is required. If a high-powered magnifying lens is used, a dark background is necessary because oligochaetes appear white after oxidation by chlorine. Again good lighting must be provided in order to limit reflection and to increase the contrast between the filter media and the oligochaetes. To avoid counting individual oligochaetes more than once, the use of Petri dishes previously cross-ruled with a pen is suggested.

The procedure for this method consists of the following steps. Samples are collected from the filter media with a core tube at different depths or with a surface sampler. Samples must be analyzed as soon as possible since heterotrophic bacteria will consume the dissolved oxygen (DO) present in the samples which may cause the oligochaetes to migrate to the surface of the samples where the DO level is sufficient for their cutaneous breathing needs (Beaudet et al. 1996; Stephenson 1930); consequently, the distribution of oligochaetes in samples may be altered. From a sample of filter media, two 4-ml media replicates are taken and placed in Petri dishes. Then, 10 ml of tap water containing some droplets (4-5) of 1% bleach solution is added to each Petri dish. This solution is obtained by diluting the 5% commercial solution. The Petri dishes are then shaken gently to promote detachment of the oligochaetes from the media grains. During this period, the oligochaetes become inert and white. After 5 minutes, the oligochaetes are enumerated

using the Darkfield Colony Québec Counter or the high-powered magnifying lens. Oligochaetes are counted twice by rotating the Petri dish through 90° after the first enumeration to ensure a greater accuracy especially when they are numerous. Oligochaete densities are calculated on a wet sample basis. The oligochaete density was expressed by the following equation (Equation 2.1):

$$\text{Oligochaete density} = \frac{\text{Number of naidids counted}}{4-\text{ml sample}} = \frac{\text{Naidids}}{\text{ml}} \qquad \text{(Equation 2.1)}$$

The statistical analysis for the method was performed with Statistica 5.1, version 97, for Windows 95 from Statsoft Inc. on a Pentium PC computer. Since the filter sample depths changed slightly from one sample to another, the depths were classified to 100-mm filter depth ranges (FD1= 0-100 mm; FD2= 100-200 mm; FD3= 200-300 mm; FD4= 300-400 mm; FD5= 400-500 mm; FD6= 500-600 mm; FD8=700-800 mm; FD9= 800-900 mm).

A Mann-Whitney U test and a Kolmogorov-Smirnov two-sample test were carried out to verify whether duplicates follow the same distribution. The Mann-Whitney U test is a nonparametric alternative to the t-test for independent samples. The interpretation of the test is essentially identical to the interpretation of the result of a t-test for independent samples, except that the U test is computed based on rank sums rather than means. The Kolmogorov-Smirnov test is another nonparametric alternative to the t-test for independent samples. Kolmogorov-Smirnov test assesses the hypothesis that two samples were drawn from different populations.

A nested analysis of variance was performed to estimate the components of the variance of the method. The total variance was divided into three components: the variation due to sampling depth (level 1), the variation due to replication (level 2) and the variation due

to oligochaete enumeration (level 3) (Figure 2.5). Finally, Tukey's honestly significant difference (HSD) test was performed to compare values of oligochaete densities obtained at different sample depths in BAC filters. It determines whether there is significant difference between oligochaete densities at different depths. This test uses a single criterion for all comparisons regardless of the distance between the group means. A significance level (α) of 5% was used for all tests.

Enumeration of oligochaetes in water samples

This second method involves a filtration column in which water is continuously collected and filtered through a 121-µm stainless-steel mesh to concentrate the oligochaetes. The filtration column was designed in such a way as to keep the oligochaetes alive in a water sample, and to prevent them from passing through the filtration column. Figure 2.6 shows a schematic of the filtration column. A plastic tube connected to the effluent pipe of the BAC filter drains water into the filtration column. The filtration duration ranged from 18 to 120 hours depending on the quality of the water being filtered. The volume of water filtered through the column ranged from 2 to 25 m^3. The flowrate of the filtered water through the column was measured using a graduated cylinder and a chronometer. Oligochaetes retained were then visually enumerated by pouring a water sample from the filtration column into a beaker under a source of light. The concentration of oligochaetes was expressed as naidids/m^3 and may be calculated by dividing the numbers of oligochaetes counted by the volume of water filtered through the filtration column.

RESULTS AND DISCUSSION

Enumeration of oligochaetes in filter media

Statistical analysis was performed on 324 samples forming duplicata collected in BAC filters during the study. Analysis was performed regardless of the sampling depth. Results have shown that duplicata follow the same distribution, according to the Mann-Whitney U test (p=0,777) and the Kolmogorov-Smirnov two-sample test (p > 0,1). Then, duplicata follow the same distribution and originate from the same population.

The components of variance of the method are presented in Tableau 2.1. According to the nested ANOVA/MANOVA test, the main component of variance is due to the sampling depth (99.9%), whereas the variance due to the duplication and the enumeration of oligochaetes was under 0.1%. Tukey's honestly significant difference (HSD) confirms this result and indicates that samples taken at the surface of the BAC filter, especially for samples taken at FD1 and for some taken at FD2, were significantly different from those taken deeper in the filter (Tableau 2.2). These results suggest that the oligochaetes were not distributed in a uniform way in the BAC filter. The means of oligochaete densities calculated over the sampling period were: μ_{FD1}=9.35, μ_{FD2}=3.50, μ_{FD3}=2.90, μ_{FD4}=1.52, μ_{FD5}=1.51, μ_{FD6}=1.78, μ_{FD8}=0.14 and μ_{FD9}=0.66 naidids/ml. The results indicate a gradient distribution with higher oligochaete densities located at the surface of the BAC filter.

Variation resulting from the replication represents a small source of variability (0.1% total variance). However, there may be an error in the volume measurement of the sample taken in the filter. The precision or the standard deviation ($\sqrt{\sigma}$) varied between 0 and 4.9 naidids/ml. The relative precision, defined as the coefficient of variation (CV), ranged from 9 to 141 % for all duplicates, for a mean of 31%. Reproducibility was generally good, but higher CVs were found for lower oligochaete densities, i.e. those under 5 naidids/ml (Figure 2.7). A higher CV was obtained when only one of the replicata

contained naidids and when oligochaete densities were close to the detection limit of the method. When oligochaete densities were higher than 5 naidids/ml, the CV was usually under 30 %, as shown in Figure 2.7. A larger sample volume of filter media could be used in order to reduce the CV at lower values and to increase the detection limit of the method. According to the method, the detection limit was estimated to 1 naidid per 4 ml or 0.25 naidid/ml.

Finally, variation resulting from the laboratory enumeration is a small source of variability (0.1%). Counting oligochaetes several times to increase the accuracy of the enumeration method could reduce this variability. When several oligochaetes are present in a sample, a source of error is introduced if any oligochaetes are counted more than once. Cross-ruled Petri dishes can be used to help to prevent this. A change of operator may also introduce a significant variation in measurement since the method depends on the operator's visual acuity. The main problem encountered with the present method is the presence of biological mud balls in which oligochaetes may be hidden. These mud balls increase the heterogeneity of oligochaete distribution at the surface. This phenomenon is common at the surface of BAC filters where filamentous bacteria are concentrated (Dubreuil 1996). Mixing samples prior to analysis to increase homogeneity is not recommended because this may cut the organisms into small pieces. Small stresses may favour segmentation by budding resulting in overestimation (Laugier 1988). A large number of media samples should be taken at the surface of the filter to estimate oligochaete densities, especially when filamentous bacteria are present.

In the present study, no other invertebrates interfere with the method. However, the method presented could also be applied or slightly modified to enumerate invertebrates, such as chironomids.

Figure 2.8 and 2.9 show typical profiles of oligochaete densities observed in cold and warm water using the method. Profiles of oligochaete densities measured in BAC filter media samples show that the highest oligochaete densities are located at the surface of BAC filters (from 0 to 0.2 m). This result may be explained by the fact that many invertebrates burrow into the substratum and hence live in close association with bacteria, which are present in sediments (Fry 1980) as well as in filter media (Bablon et al. 1986). Moreover, some species of naidids feed on heterotrophic and aerobic bacteria and live at the interface of the water and sediment (Brinkhurst and Gelder 1991). In Figures 2 and 3, the highest oligochaete densities at the top of the filter were 3 ± 1 naidids/ml in cold water and 17 ± 1 naidids/ml in warm water. Throughout the study, the highest oligochaete densities were recorded in warm water (~25 naidids/ml, t = 25°C) in the surface layer of the filter media, while the lowest densities were observed in cold water (t = 1°C) at values near or under the detection limit of the method at the same depth. Generally, deeper within the filter, oligochaete densities decreased to below 1 naidid/ml. Therefore, the proposed method permits easy evaluation of the population of oligochaetes in BAC filters from samples taken at different depths.

Enumeration of oligochaetes in water

Oligochaete concentrations recorded at the effluent of a BAC filter using a filtration column varied from the detection limit to 20 naidids/m^3 during the sampling period. Before June 24, 1996, no oligochaetes were found in water samples. The peak value was observed on June 27, 1996 at a value near 20 naidids/m^3 in the BAC effluent. The temperature of the water had increased during this period from 19°C to 21°C. The average oligochaete concentration in the filtered BAC water during the sampling period was estimated to be 6.7 naidids/m^3 between June 21, 1996 and July 12, 1996. The hypothesis assumes that the samples were representative of the effluent of the BAC filter.

Considering the low concentrations of oligochaetes found, it appears that only a continuous method is suitable for estimating concentrations of oligochaetes with some accuracy. However, with the use of the method, short-term changes affecting concentrations of oligochaetes can not be monitored.

Furthermore, the method proposed was initially devised to concentrate mature organisms and was not designed to retain cocoons or eggs produced by oligochaetes. Oligochaetes may reproduce sexually by means of cocoons containing eggs or asexually by means of fragmentation regulated by the time of the year (Brinkhurst and Gelder 1991; Stephenson 1930). Depending on the size of the cocoons and the time required for their development, they may be retained and may hatch into the filter or even in the filtration column of the sampling device.

CONCLUSION

This study has shown that the enumeration of oligochaetes in filter media samples can be achieved. A statistical analysis of the sources of variance of the data (n=324) has shown that the counting and replication errors are negligible compared to the variation in oligochaete densities encountered in the BAC filter.

The enumeration of oligochaetes in the filter media samples taken at different depths can be used to monitor the population of oligochaetes in BAC filters in drinking water treatment plants. Even if BAC filters are colonized overall by oligochaetes, a sample taken at the surface of the filter media could be a good indicator of the level of colonization in biological filters. However, if filamentous bacteria in media samples are present, special attentions should be given to take into account the potential impact of oligochaete densities in mud balls.

Experimental results of the enumeration of oligochaetes in water samples have shown that the filtration column devised can concentrate oligochaetes to evaluate the concentration of oligochaetes in the effluent of BAC filters.

Finally, the simple methods proposed in this paper could be used to monitor the population of oligochaetes in BAC filters and in their effluent. Simple and cost-effective, these methods can be easily applied in drinking water treatment plants, which have invertebrates in their filters.

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Tableau 2.1 Variance components for the method of enumeration of oligochaetes in a filter media

Variance	Ms Effect (naidids/ml)²	F values	P-level	Percentage of total (%)
$\sigma^2_{\text{sampling depth}}$	829.4615	65.6872	**0.0000**	99.9
$\sigma^2_{\text{replication}}$	0.5921	0.04689	0.9999	0.01
$\sigma^2_{\text{enumeration}}$	0.0840	0.00665	1.0000	0.00
σ^2_{total}	1125.64	--	--	100.00

Tableau 2.2 Results of Tukey's HSD test for collected data for the method of enumeration of oligochaetes in a filter media

Filter Depth	**FD 1**	**FD 2**	**FD 3**	**FD 4**	**FD 5**	**FD 6**	**FD 8**	**FD 9**
FD 1	--	**0.00003***	**0.00003***	**0.00003***	**0.00003***	**0.00003***	**0.00003***	**0.00003***
FD 2	--	--	0.92984	**0.03453***	**0.00348***	0.137289	**0.00012***	**0.00033***
FD 3	--	--	--	0.35930	0.13775	0.675941	**0.00352***	**0.01303***
FD 4	--	--	--	--	1.00000	0.99992	0.54143	0.88627
FD 5	--	--	--	--	--	0.99989	0.55608	0.89548
FD 6	--	--	--	--	--	--	0.30921	0.66483
FD 8	--	--	--	--	--	--	--	0.99641
FD 9	--	--	--	--	--	--	--	--

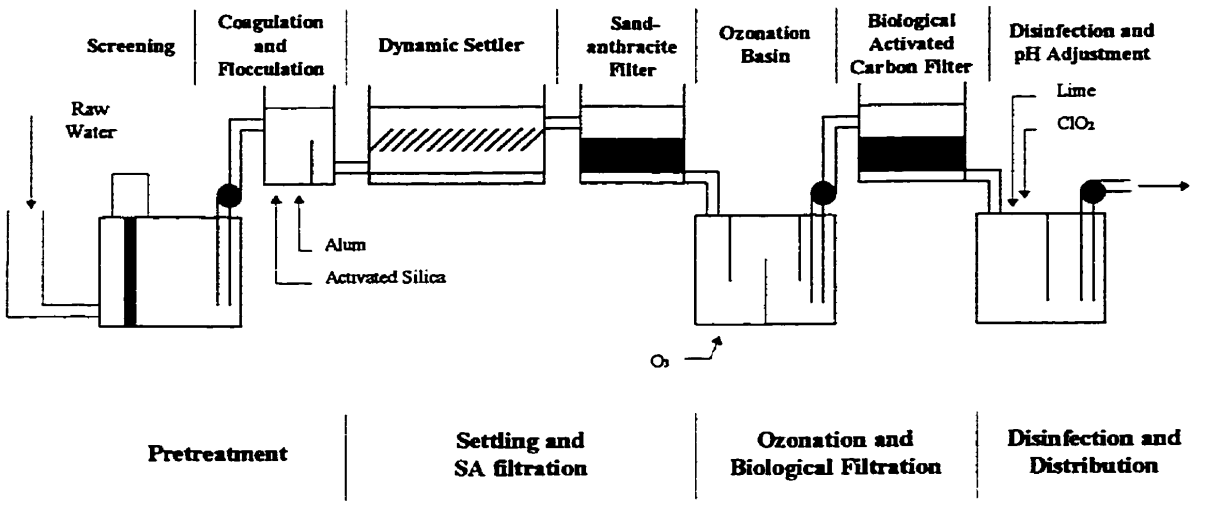

Figure 2.1 Schematic flow diagram of Ste. Rose Filtration Plant (110,000 m³/d)

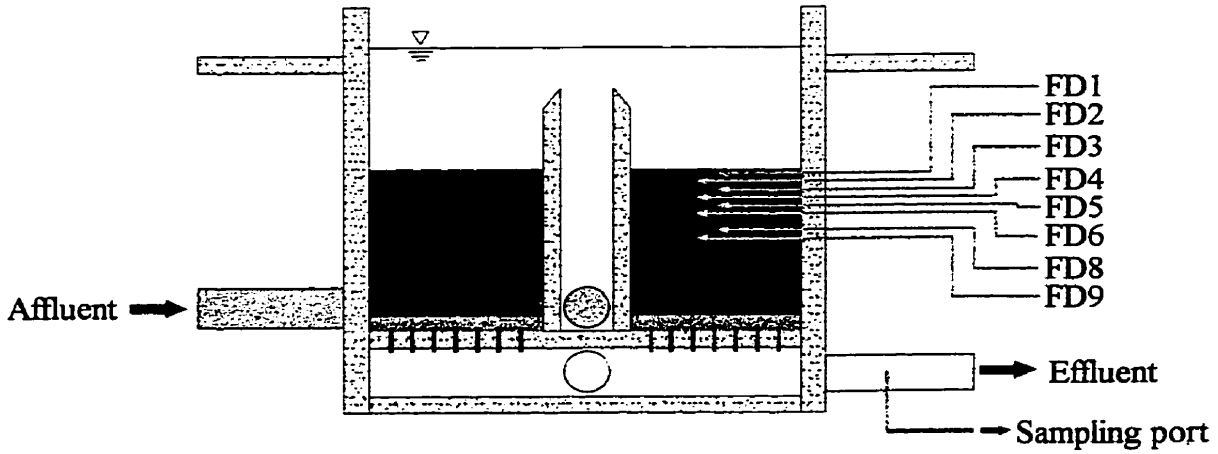

Figure 2.2 Liquid and solid sampling locations in the BAC filter

Figure 2.3 Naidid viewed by bright-field microscopy, 100X

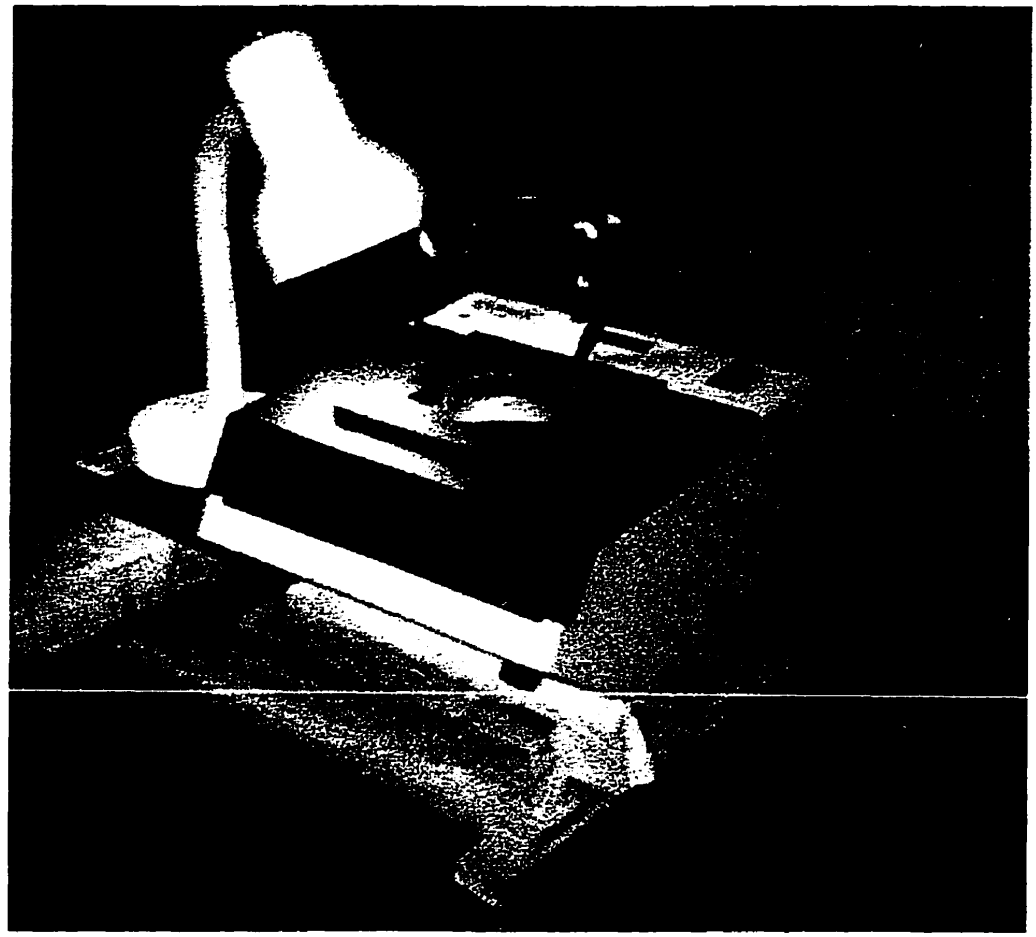

Figure 2.4 Equipment used for oligochaete enumeration in a sample of filter media

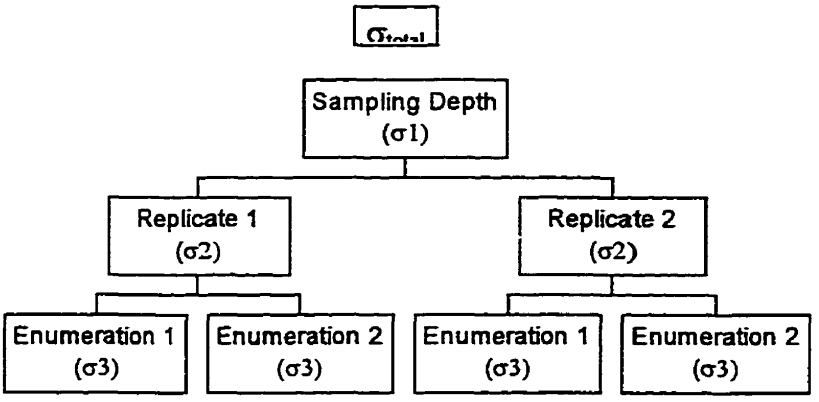

Figure 2.5 Statistical design analysis for the enumeration of oligochaetes in filter media

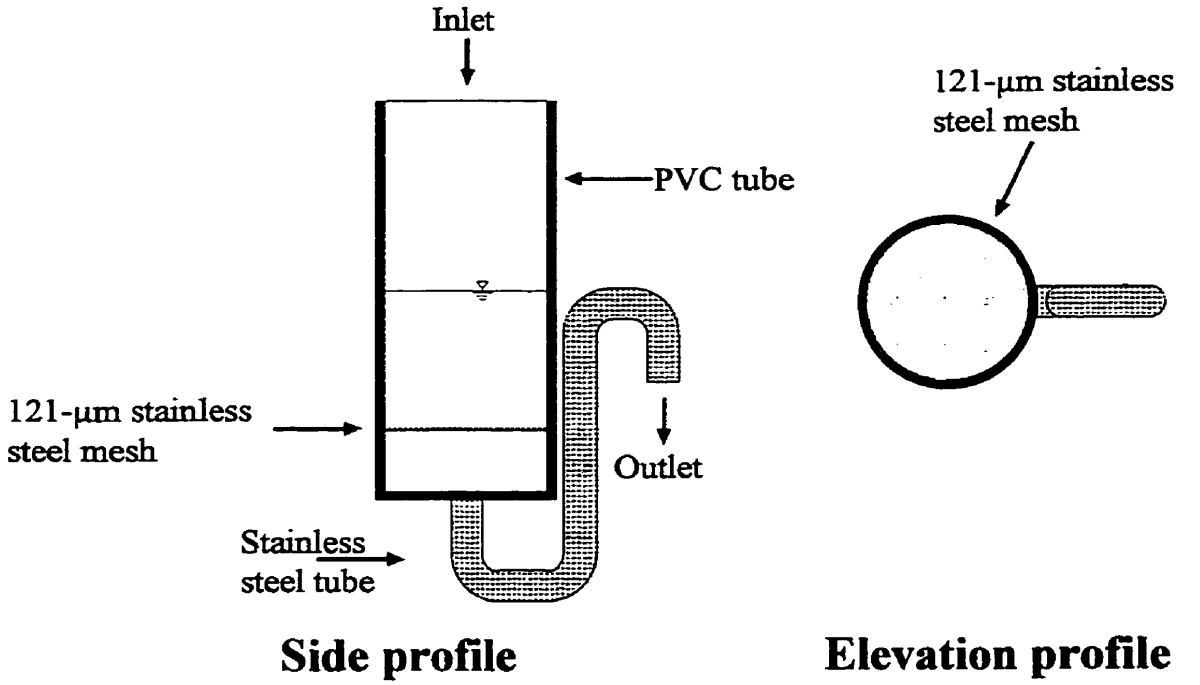

Figure 2.6 Schematic of a filtration column used for the enumeration of oligochaetes in water

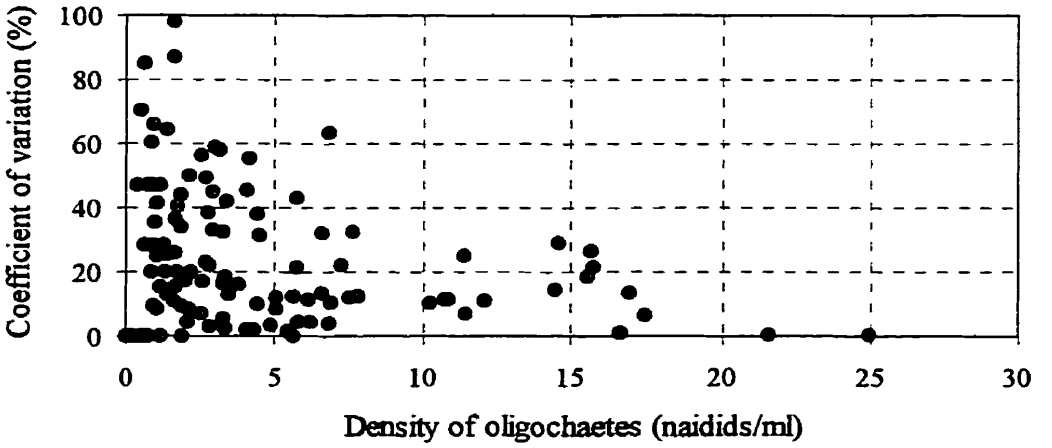

Figure 2.7 Relationship between the density of oligochaetes and the coefficient of variation (CV) for data collected in 1995 and 1996

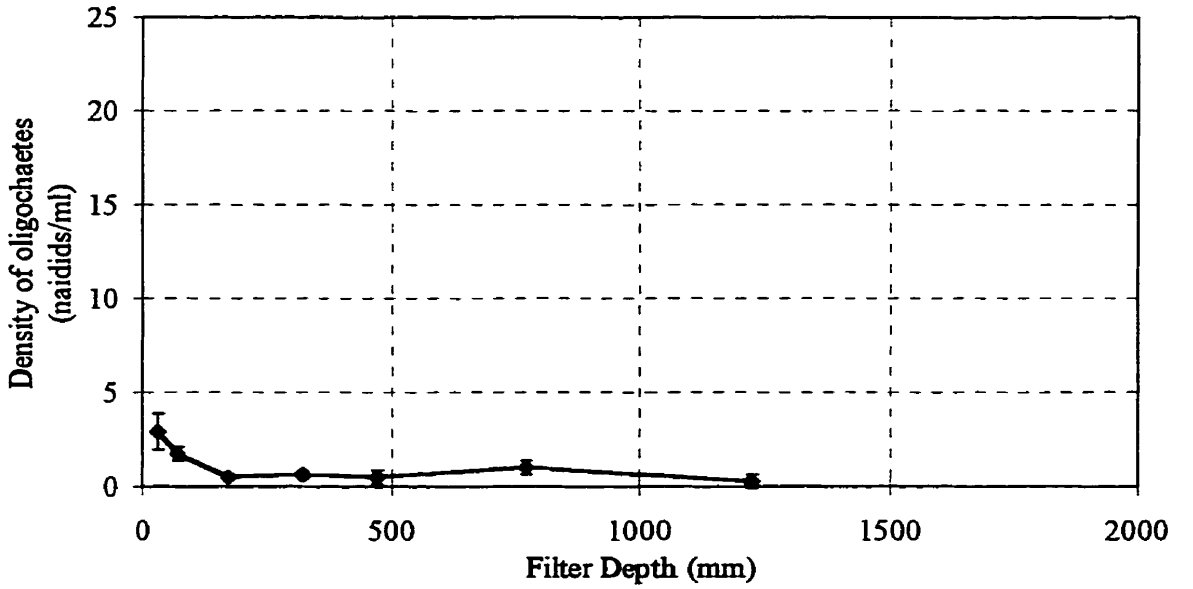

Figure 2.8 Profile of oligochaete densities in cold water (t=1°C; December 12, 1995; 96-h frequency of backwashing; error bars are standard deviation)

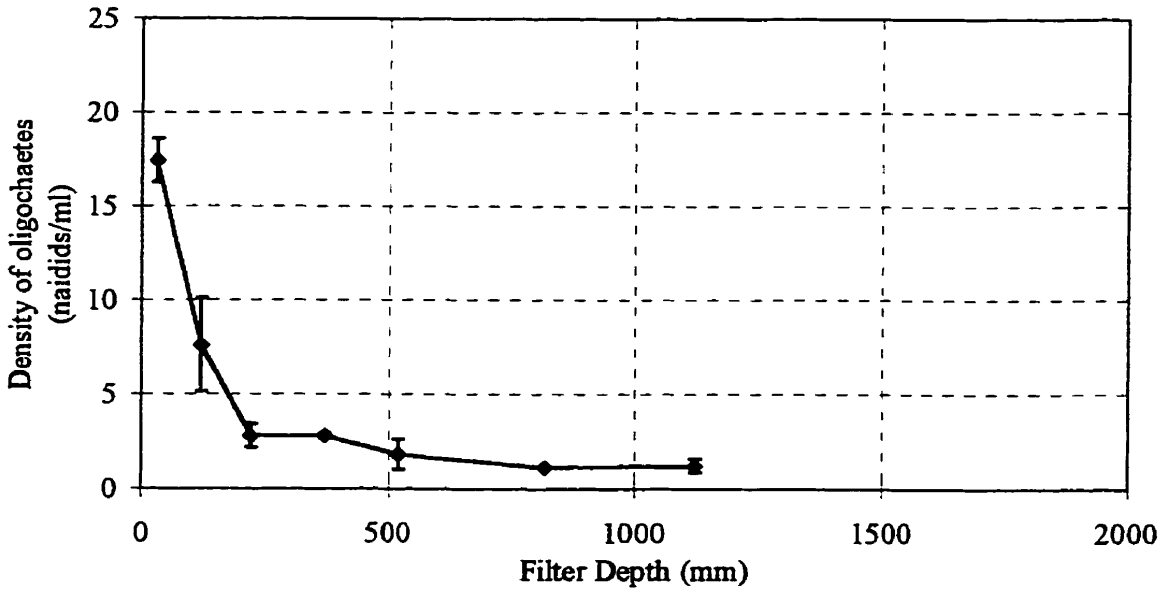

Figure 2.9 Profile of oligochaete densities in BAC filter in warm water (t=22°C; September 5, 1995; 96-h frequency of backwashing; error bars are standard deviation)

2.3 CONCLUSION

L'estimation des densités d'oligochètes dans des échantillons de milieux filtrant a permis de constater que la méthode est précise et reproductible. Le coefficient de variation de la mesure est estimé à moins de 30% lorsque les échantillons contiennent des densités d'oligochètes supérieures à 5 naïdides/ml. Les densités d'oligochètes mesurées durant l'ensemble de l'étude ont varié entre la limite de détection et 25 naïdides/ml. Par ailleurs, les analyses statistiques ont montré que les densités d'oligochètes les plus importantes étaient situées en surface des filtres CAB en eaux froides comme en eaux chaudes. Les analyses ont enfin montré qu'à une profondeur supérieure à 300 mm, les densités d'oligochètes étaient significativement plus faibles et généralement inférieures à 2 naïdides/ml. La principale source de variation de la variable densité d'oligochètes est la profondeur à laquelle les échantillons sont prélevés. La réplication et le dénombrement des oligochètes représentent des faibles sources de variation de la méthode.

L'estimation des densités d'oligochètes dans des échantillons d'eau filtrée en continu a mis en évidence que les naïdides pouvaient être énumérés à la sortie des filtres CAB. La concentration moyenne de naïdides à l'effluent des filtres CAB a varié entre 0 et 20 naïdides/m^3 durant l'étude. Comme les prélèvements sont effectués sur des longues périodes de temps, la méthode peut ne pas être sensible à des phénomènes de courtes durées.

A l'aide des méthodes de mesure développées et proposées, les périodes de l'année durant lesquelles les oligochètes sont présents dans les usines de traitement d'eau potable pourront être déterminées. Des techniques de contrôle actives et proactives des populations d'oligochètes pourront ensuite être appliquées.

CHAPITRE 3: SUIVI ANNUEL DES POPULATIONS D'OLIGOCHÈTES DANS LES FILTRES À CHARBON ACTIF BIOLOGIQUE DES USINES DE TRAITEMENT D'EAU POTABLE

3.1 INTRODUCTION

Ce chapitre présenté sous forme d'article à la section 3.2 présente les résultats obtenus lors du suivi des oligochètes dans les filtres CAB ainsi que dans la chaîne de traitement de l'usine de traitement d'eau potable Sainte-Rose de Laval. Ces recherches ont été réalisées en 1995 et 1996.

Grâce au développement de méthodes de mesure plus sensibles et plus précises pour l'évaluation des populations d'oligochètes en usine présenté au chapitre précédent, l'étude s'est d'abord penchée sur l'identification des périodes durant lesquelles les oligochètes pouvaient être détectés dans les filtres CAB de l'usine. En effet, c'est dans les filtres CAB que les populations d'oligochètes les plus importantes ont été observées. Les profils de densités d'oligochètes dans les filtres CAB ont donc été effectués durant près d'un an dans cette perspective. Dans un second temps, un suivi plus intensif des densités d'oligochètes dans la chaîne de traitement de l'usine a été réalisé pour la période durant laquelle les oligochètes sont présents en grand nombre dans les filtres CAB, soit au cours des mois de juin et juillet.

L'ensemble des résultats de cette recherche est présenté sous forme d'article. L'article a été soumis au *Journal of American Water Works Association* en août 1998.

3.2 OCCURRENCE OF OLIGOCHAETES IN DRINKING WATER TREATMENT PLANTS

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ABSTRACT

The objective of this study was to determine the periods during which oligochaetes are present in the Ste. Rose drinking water treatment (City of Laval, Québec, Canada). For nearly a year, plant-scale density profiles were created for oligochaetes in a biological activated carbon (BAC) filter. These oligochaetes were belong to the naidid family.

During the winter period, when the temperatures of the water approach 0°C, oligochaetes are not detected in treatment plants or in BAC filters themselves. However, at the beginning of June, when suitable environmental conditions begin to develop and the temperature of the water reaches 20°C, oligochaetes start to appear in BAC filters. The oligochaete densities measured in filters then increase rapidly, reaching values of up to 25 naidids/ml. During the summer season, the oligochaete population remains relatively constant, having probably reached a state of equilibrium. The asexual reproduction of naidids is probably responsible for the increase and the maintenance of the population of oligochaetes in BAC filters, while sexual reproduction enables the species to survive during the unfavourable conditions encountered during the winter. Throughout the study, the oligochaete densities were always higher at the surface of BAC filters than deeper within them. The temperature of the water and the presence of an adequate food source are the principal factors influencing the population of oligochaetes in natural environments as well as in BAC filters.

Monitoring the presence of oligochaetes at different points in the drinking water treatment system during the period of colonization of the BAC filters by oligochaetes during the month of June indicated that oligochaetes can be detected in the effluent of the SA filters and in the effluent of the BAC filters at concentrations which vary between 0 and 20 naidids/m^3. The highest oligochaete concentrations were measured in the effluent of the BAC filters. No oligochaetes were detected in the raw water and they were detected only during few days in the settled water. Oligochaetes were counted in the

effluent of the BAC filters only when the oligochaete densities were higher than 5 naidids/ml on the surface of the filters.

INTRODUCTION

Macro-organisms are found in many water utilities all around the world and are often the source of problems for the drinking water community. A survey of nuisance organisms was conducted in 1989 by the Organisms in Water Committee of the American Water Works Association to determine the extent of problems encountered by water utilities due to the presence of organisms in water. Algal cells, iron bacteria, actinomycetes and sulfur bacteria were identified as the greatest sources of taste-and-odor, whereas midge larvae and other types of larvae were problematic from an aesthetic point of view, the consumer being the one usually discovering the problem (AWWA 1995). In Europe, invertebrates have been monitored in the surface water supplies for several decades. A two-year national survey on invertebrates in drinking water distribution systems started in 1993 in the Netherlands investigated the occurrence of invertebrates in water produced from surface water and ground water. Preliminary results have shown that invertebrates were found in all participating water supplies (van Liverloo et al. 1994). The same study revealed that organisms have been found leaving treatment plants, in flushing water and in tap water.

Recent studies have shown that the combination of biological filtration preceded by an ozonation step may improve the bacterial and physico-chemical stability of drinking water substantially by reducing bacterial regrowth potential and the formation of disinfection by-products (DBPs) in drinking water (Bablon et al. 1986; Prévost et al. 1989; Servais et al. 1987; van der Kooij et Hijnen 1984). Many water utilities are now considering biological activity in the treatment plant especially in the filters, as a desirable process. However, the use of biological filters may favour the settlement and the development of predators of the bacterial biomass established in filters. Filtration on activated carbon

supports, also referred to as biological activated carbon filtration, optimizes this biological activity by providing attachment sites for bacteria (Prévost et al. 1991; Servais et al. 1994). Hence, the levels of biomass reached in BAC filters are often higher than those observed in conventional filters (Miltner et al. 1992; Wang et al. 1995). Biologically active filters, and especially BAC filters, may be a suitable environment for supporting higher forms of organisms in filters, such as chironomids, nematodes or oligochaetes.

The presence of macro-organisms in distribution systems has been linked to the growth of macro-organisms in drinking water treatment plants. For example, oligochaete worms that grew abundantly in the sand filters of the Rotterdam water supply in the Netherlands were found at the consumer's tap in 1964 (Rook 1970). However, no study has investigated the impact of biological treatment on the passage to, and the occurrence of macro-organisms, in distribution systems.

If macro-organisms passed through filters, then the wide trophic chain of micro-organisms that exists in distribution systems could possibly support their growth (Amblard et al. 1996). In addition, some species of invertebrates found in natural habitats, such as oligochaetes, have been shown to have bacteria growing on their surface, up to 3.0×10^5 bacteria per naidid (Chatarpaul et al. 1980; Harper et al. 1981). It is therefore essential to prevent the proliferation of invertebrates in filters in order to limit their presence in the filtered water and, consequently, in distribution systems.

At the Ste. Rose drinking water treatment plant (City of Laval, Québec, Canada), oligochaetes colonize biological activated carbon (BAC) filters during most of the year except in cold water. The seasonal occurrence of oligochaetes in drinking water treatment plants has been documented by monitoring the densities of oligochaetes in BAC

filters for a nearly a year and the concentrations of oligochaetes at different step in the treatment process during the colonization of these filters.

OBJECTIVES

This study focuses on the occurrence of oligochaetes in drinking water treatment plants by monitoring the population of oligochaetes: 1) in biological filters, and 2) at different locations through out the treatment train during the period of colonization of biological filters. Prior to devising an effective strategy to control the population of oligochaetes, it is important to determine the periods during which oligochaetes can be observed in drinking water treatment plants. Once established, reactive and proactive control measures can be applied to limit the presence of oligochaetes in water utilities, especially in drinking water treatment plants.

MATERIAL AND METHODS

The experiment was conducted at the Ste. Rose drinking water treatment plant (City of Laval, Québec, Canada). Its nominal capacity is 110,000 m^3/d. A schematic flow diagram of the Ste. Rose plant is illustrated in Figure 3.1. The facility includes screening, coagulation-flocculation-settling, filtration on sand and anthracite (10-m/h superficial velocity), ozonation (0.4 mg O_3/l after 10 minutes), filtration on biological activated carbon (10-m/h superficial velocity), disinfection by chlorine dioxide and final pH adjustment to 7.3-7.6.

The filtration plant draws its water from the Mille Iles River which has a high organic load and a low alkalinity. The Mille Iles River is fed by the Lake of Deux-Montagnes, which is supplied by the Ottawa River in the St. Lawrence Basin. Typical seasonal parameters of raw water are shown in Tableau 3.1. Over one year, the temperature of the raw water ranges from 0.1 to 28°C, the turbidity from 2.0 to 75.0 NTU, and the

alkalinity from 20 to 47 mg $CaCO_3$ /l. The oligochaetes found in the treatment plant and enumerated in samples were belong to the naidid family (Beaudet 1998).

The technique used to enumerate oligochaetes in filter media samples has been described by (Beaudet et al. 1996). A core tube was used to extract samples from the BAC filter at different depths symbolized by FD (Figure 3.2). The BAC filter sampled had a 0.3-m layer of sand underneath a 1.5-m activated carbon layer. Media samples were collected during the period from August 1995 through September 1996. The estimated detection limit was 1 naidid per 4 ml of wet filter media.

The enumeration of oligochaetes in water samples was achieved using a filtration column in which water was filtered through a 121-µm stainless steel mesh to concentrate the oligochaetes and to keep them alive as described by (Beaudet 1998). Water samples were collected at different locations in the treatment train: raw water, settled water, sand and anthracite (SA) filtered water and BAC filtered water. The volume of filtered water was determined from filtration time and flowrate through the filtration column and ranged from 3 to 25 m^3 depending on the sampling location in the treatment train. Water samples were taken in October 1995 and in June and in July 1996.

The statistical procedures used to analyze the data were performed with Statistica 5.1, version 97, for Windows 95 from Statsoft Inc. on a Pentium PC computer. 3-D surfaces showing variations of oligochaete densities as a function of the time of the year and of the filter depth were computed with a negative exponential smoothing using a 0 stiffness and no optimization. 3-D surfaces were sketched with Statistica 5.1, version 97 for Windows 95 from Statsoft Inc..

RESULTS

Monitoring oligochaetes in the treatment plant

The oligochaete densities in water at different locations in the treatment plant from June 18, 1996 to July 12, 1996 are presented in Figure 3.3. No oligochaetes were found in the raw water during the sampling period. Oligochaetes were detected exclusively in the settled water between June 17, 1996 and June 19, 1996 at levels below 4 naidids/m³. Oligochaetes were found in the SA filter effluent for the first time on June 18, 1996 and were still present until July 12, 1996 (1 naidid/m³ or fewer). The highest concentration of oligochaetes recorded during the sampling period was observed in the effluent of the BAC filter on June 24, 1996. Results showed that the concentration of oligochaetes in the effluent of the BAC filter increased rapidly from the detection limit (0 naidid/m³) on June 18, 1996 to 20 naidids/m³ on June 27, 1996. Then, concentrations of oligochaetes began to decrease, to 2.5 naidids/m³ on June 12, 1996. During this period, the temperature of the water increased from 19°C to 23°C and the frequency of filter backwashing was maintained at 96-hour intervals. Other results showed similar concentrations of oligochaetes (up to 2.1 naidids/m³ in the effluent of the BAC filters in October 1995).

Monitoring oligochaetes in the BAC filter

Profiles of oligochaete densities in the BAC filter studied show that oligochaetes were present during more than half the year. Figure 3.5, 3.5, 3.6 and 3.7 illustrate the changes in population of oligochaetes in the first 1000-mm filter depth. Data for deeper filter depths are not presented with these figures based on the fact that previous results showed low oligochaete densities at these depths as 2 naidids/ml or fewer (Beaudet 1998). Blue points shown on 3-D surfaces correspond to the raw data. Figure 3.5 and 3.6 exhibit profiles of oligochaete densities between September and December 1995 for a water temperature ranging from 22 to 11°C and from 11 to 1°C respectively. The profiles of oligochaete densities indicate that the population decreased as the temperature dropped in

the autumn. During this period, the highest oligochaete densities (25 naidids/ml) were recorded in September in warm water (t = 25°C) and were located at the surface of the BAC filters. The lowest densities at the surface of the BAC filter were observed when the temperature of water reached 0.5°C in December 1995. The frequency of filter backwashing changed as the water temperature dropped from every 48 hours in September 1995 to every 72 hours in October 1995 and finally to every 96 hours at the beginning of November 1995.

Between January and the beginning of June 1996, oligochaetes were not detected in the BAC filter (detection limit of 1 naidid/4 ml). During this period, the temperature of the water increased from 0.5°C to 19°C and the interval between filter backwashings was over 96 hours.

From June 12, 1996, oligochaetes were found in the BAC filter studied when the temperature of the water reached 20°C. Figure 3.4 and 3.7 show profiles of the oligochaetes densities during this period. According to these figures, the colonization of the BAC filter by naidids proceeded rapidly taking less than four weeks. Populations of oligochaetes in July 1996 reached similar levels than those recorded one year before, in September 1995. The interval between filter backwashings was fixed to 96 hours during this period.

DISCUSSION

Presence of oligochaetes in the treatment train

No oligochaetes were observed in the raw water during the sampling period. Two hypotheses may explain this result. On the one hand, it is probable that the oligochaetes present in the raw water enter the plant in cocoon form at the beginning of June prior to the development of the environmental conditions that are favourable to them. On the other hand, it may be that adult naidids were present in too weak a concentration in the

raw water to be detected there, but their number was sufficient to ensure that the species would reproduce in favourable conditions. The volume of raw water sampled was probably not sufficient to permit them to be counted in a routine way. Similar sampling problems have already been encountered with respect to this type of organism under similar conditions by other authors, but in natural environments (Learner et al. 1978).

Sexual reproduction by means of cocoons constitutes one of the two methods of oligochaete reproduction, the other being asexual reproduction by segmentation or fragmentation. This second method is observable during most of the year (Brinkhurst et Gelder 1991), and manifests itself by the division of one naidid into two distinct individuals.

Generally, asexual reproduction predominates, but sexual reproduction makes the survival of naidids possible during periods when environmental conditions are unfavourable to them (Stephenson 1930). The characteristics of the water, such as temperature and salinity, are, in addition to the presence of an adequate food source, the principal parameters influencing the levels of the naidid population during the year in natural environments (Learner et al. 1978; Loden 1981; Timm 1980). These parameters are linked to variations in annual climatic conditions, which themselves influence the methods of reproduction of naidids.

In most naidids, extreme winter and summer weather is responsible for sexual reproduction. In the United States, for example, sexual reproduction is principally observed from May to July, but also in September and October, depending on the species and the geographical region in which they live (Loden 1981). In southern regions, where summers are drier and hotter, sexual reproduction occurs in the spring or at the beginning of the summer. By contrast, in the north, in regions where winters are cold and severe, sexual reproduction is observed in the autumn and at the beginning of the winter, while

asexual reproduction is dominant during the summer (Loden 1981). It is probably this latter phenomenon that is being observed at the Ste. Rose treatment plant. Naidids reproduce sexually during the winter period once unfavourable conditions have developed in the autumn (lowering of temperature, absence of food sources, etc.), thus reappearing in significant numbers in rivers and in treatment plants in June. Oligochaetes could therefore enter the treatment plant, either in cocoon form or in the form of adult naidids, and then be partially stopped in the treatment train. The SA and BAC filters would thus act as a physical, but only partial, barrier for cocoons or individuals coming from raw water. Dynamic sludge blanket settlers would play a similar role. However, since BAC filters provide highly favourable surroundings for their reproduction, naidids should be found in greater numbers in the effluent of these filters.

The fact that naidids were first observed in the BAC filter at the beginning of June (Figure 3.4, 06/12/96), before they had even been counted upstream (Figure 3.3, 06/17/96), suggests two possible hypotheses: either adult naidids were present in too weak a concentration to be counted during sampling, or naidids were entering the treatment plant in cocoon form. In both cases, however, adult naidids or cocoons crossed the SA filters, resisted the ozonation step and then colonized the BAC filter. The size of the naidids observed at the Ste. Rose plant varied between 1 and 2 cm in length. Similar sizes for naidids have been reported in natural environments in previous studies (Harper et al. 1981). The same authors report that the average diameter of naidids was 0.15 mm. Consequently, mature individuals can cross SA and BAC filters and be present at the origin of the process of colonization of BAC filters. During the sampling period, no lack of ozone was recorded at the treatment plant (ozone residual of 0.4 mg O_3/l after 10 minutes).

Finally, naidids have been counted in the effluent of the BAC filter only when the oligochaete population in the filters has reached a certain threshold. For the BAC filter at

the Ste. Rose plant, naidids could be counted in the effluent of this filter when the oligochaete density at the surface reached more than 5 naidids/ml (Figure 3.3 and 3.4). Consequently, the presence of oligochaetes in the effluent of the BAC filter should be observable as long as the oligochaete population is colonizing this filter but beyond a certain threshold.

Monitoring the oligochaete density profiles in the BAC filters

Based on all the oligochaete density profiles created during the study, the data show unequivocally that oligochaetes are located principally at the surface of BAC filters. These results have also been studied statistically in previous works (Beaudet 1998). To explain this phenomenon, we must consider the feeding mechanisms of oligochaetes. Certain species of naidids feed on aerobic and heterotrophic bacteria (Brinkhurst et Gelder 1991). Other studies have shown that naidids cross filters better in environments supporting greater bacterial activity (Lochhead et Learner 1983). So, for gravity-operated biological filters, the highest values of fixed biomass density are located at the surface, as long as the filtration process has not preceded to a pre-chlorination step (Lu et Huck 1993; Niquette et al. 1998; Wang et al. 1995). Samples taken at the surface of BAC filters have, however, revealed the presence of filamentous bacteria in significant amounts relative to quantities found in samples taken from lower depths (Dubreuil 1996). These bacteria are a food source for naidids: filamentous bacteria have been observed inside the digestive tract of a naidid with the help of a phase-contrast microscope.

The oligochaete density profiles presented in Figure 3.5, 3.6 and 3.7 show seasonal variations in the population of naidids in the BAC filter at the Ste. Rose plant. These results show that the population of naidids in the BAC filter decreases progressively as the temperature of the water diminishes between September and December (Figure 3.5 and 3.6). In effect, colder temperatures slow down the process of asexual reproduction of oligochaetes to the point of stopping it, thereby favouring sexual reproduction (Timm

1980). The increase in oligochaete densities observed towards the end of October could, however, be attributable to the increase in the duration of filtration cycles, which would promote the accumulation of filamentous bacteria at the surface of the BAC filter and then would permit the asexual reproduction of naidids to occur in more favourable conditions (Figure 3.5). The duration of the filtration cycles was, in fact, modified during the period in which the naidid population in the BAC filters was being monitored. In September, it was 48 hours; at the beginning of October, it went from 48 hours to 72 hours; at the beginning of November, it stabilized at 96 hours and remained there until the end of December 1996. The temperature of the water varied during this period from 21 to 17°C at the end of September, to 11°C at the end of October and to 1°C at the end of November. Longer duration of filtration cycles could then have an impact opposite to that of the temperature of the water, even though only a slight one. Other work in this vein will attempt to evaluate the impact of the duration of filtration cycles on oligochaete populations in BAC filters.

The reason for the absence of naidids in the BAC filter during the winter months is that conditions prevail at this time that are unfavourable to the development of naidids. During this period, the cold water and the absence of an adequate source of food probably reduce the rate of growth and of reproduction of naidids. Under these unfavourable conditions, sexual reproduction becomes essential to the survival of the species (Loden 1981). Sexual reproduction by naidids was not studied at any time during this research, however.

Asexual reproduction in the middle of June, once favourable environmental conditions had developed in the BAC filter, explains the rapid increase in the population of naidids at the Ste. Rose filtration plant. The oligochaete population in the BAC filter increases rapidly when the temperature of the water reaches about 20°C (Figure 3.4 and 3.7). The development of a trophic chain, which is essential to the growth of naidids in the BAC

filter, could explain the rapid increase in oligochaete densities in the filter medium. Indeed, the population of certain species of naidids can double in the space of 4 to 6 days once the temperature has reached 20°C in conditions favourable to their growth (Lochhead et Learner 1983). This increase in population would then be attributable to the asexual reproduction of naidids in BAC filters, as observed in June 1997, on specimens taken from one of the filters, since the maintenance or increase in the population of naidids must be achieved by asexual reproduction under favourable environmental conditions (Loden 1981).

Based on calculations and data collected during the sampling period, it is possible to determine if the increase in oligochaete densities in the BAC filters is due primarily to oligochaetes coming from SA filters, rather than to the asexual reproduction of naidids. During this period, the mean daily flowrate at the plant was about 60,000 m^3/d spread out over 6 filters of 84 m^2. If the concentration of oligochaetes at the outflow of the SA filters corresponds to a mean value of 1 naidid/m^3, estimated on the basis of the data collected, then the oligochaete load received by the BAC filters is evaluated at 10,000 naidids per day per filter. Supposing that all the naidids are stopped in the first 10 cm of the filter, since we know that the oligochaetes are located at the surface of BAC filters, we find that the oligochaete density corresponds to 0.001 naidid/ml. Considering a period of 6 days, which is the time interval between two oligochaete density profiles (carried out on June 12, 1996, and June 18, 1996) and considering the impact of backwashing the filters to be negligible, then the increase in the oligochaete density, calculated based on the naidid load coming from the SA filters, is close to 0.005 naidids/ml, which is 400 times lower than the increase observed during the sampling period (increase of 2 naidids/ml between June 12, 1996 and June 18, 1996 at the surface). This suggests that the number of adult naidids observed in the effluent of the SA filters in the middle of June does not constitute the source of the increase in oligochaete densities in the BAC filter. The rapid increases in oligochaete density measured in the BAC filter

seems to confirm that asexual reproduction is the principal method of reproduction of naidids, since the densities double about every 6 days during the month of June. The increase in the population of naidids is, however, slowed down when the population in the BAC filter reaches a point of equilibrium in the month of July.

CONCLUSION

All filters are colonized by bacteria at different levels. When suitable conditions are provided, invertebrates such as oligochaetes may settle in conventional and biological filters. Temperature and food supply are the mains factors affecting the population of oligochaetes in natural habitats as well as in BAC filters.

In cold water (0.5°C), naidids were not detected in the BAC filter but appeared rapidly in the spring when the temperature of the water reached 20°C. Naidids then colonized and settled in the BAC filters until the next cold season. Naidids reproduced during the warm season by asexual reproduction, by fragmentation. The highest oligochaete densities were measured at the surface of the BAC filters. Deep within the filters, oligochaete densities were 2 naidids/ml or fewer. When present in the filters at level at the surface higher than 5 naidids/ml, oligochaetes passed through the filters. In that case then, an effective post-disinfection is necessary to prevent them from entering in distribution systems.

To limit the presence of oligochaetes in drinking water treatment plants as well as in distribution systems, control measures should be developed. New filter backwashing techniques could be studied and tested.

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Tableau 3.1 Ranges of physico-chimical and bacteriological parameter values for the Ste. Rose raw water from the Mille Iles River (Laval, Québec, Canada)

Parameters	Seasons			
	Spring	Summer	Autumn	Winter
Temperature (°C)	0.3-25.4	15.9-28.0	0.4-18.2	0.1-0.3
PH	7.0-7.6	6.7-8.1	7.1-7.6	7.0-7.5
Turbidity (NTU)	2.0-56.0	2.0-12.2	2.8-75.0	2.0-8.9
Color (ACU)	41-328	28-91	40-328	41-85
Alkalinity (mg $CaCO_3$/l)	20-47	23-38	19-39	20-45
Hardness (mg $CaCO_3$/l)	28-64	30-51	31-59	26-67
TOC (mg C/l)	5.5-6.9	5.8-7.1	5.8-8.3	5.5-7.8
DOC (mg C/l)	5.4-6.9	5.3	6.4-7.2	5.4-6.9
BDOC (mg C/l)	0.3-0.7	0.7	0.7	0.1-0.4
HPC/100 ml	1,000,000			
Total Coliforms (CFU/100 ml)	1,000- 20,000			

*Source : City of Laval (1987-1995) and Dubreuil 1996

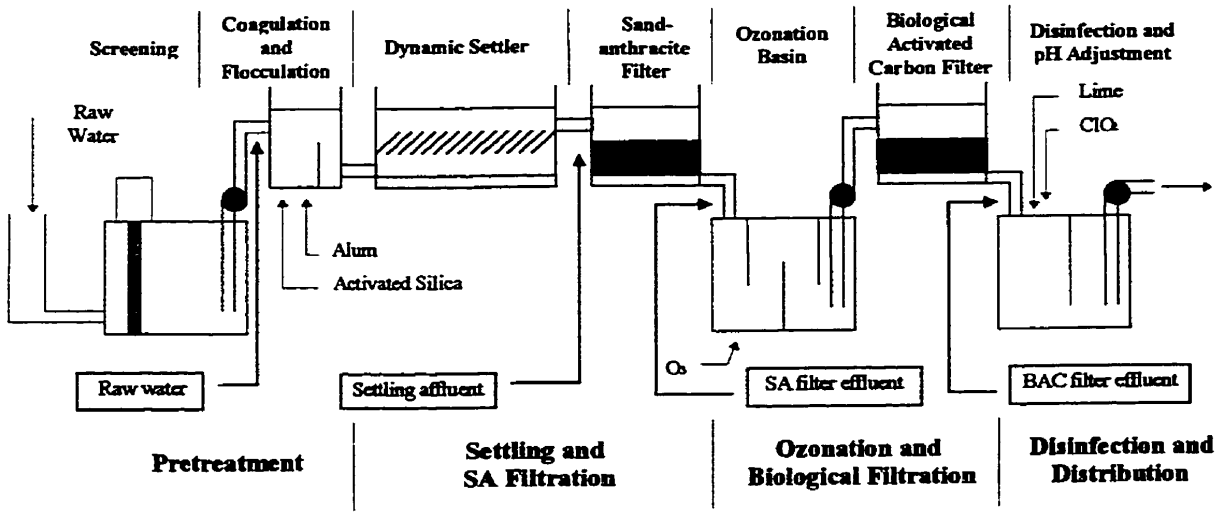

Figure 3.1 Schematic flow diagram of Ste Rose treatment plant and sampling port locations for water samples (City of Laval, Québec, Canada)

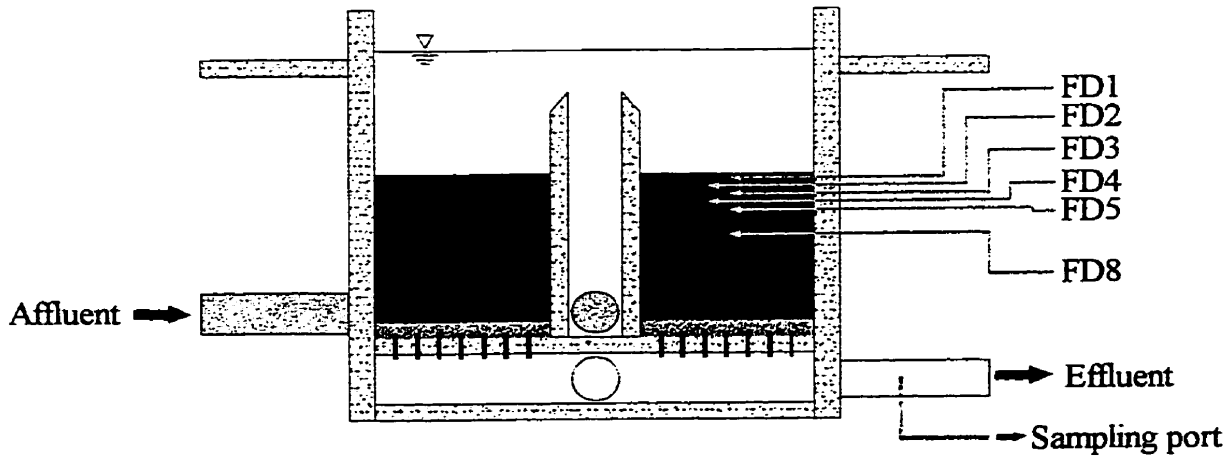

Figure 3.2 Liquid and solid sample locations in the BAC filter

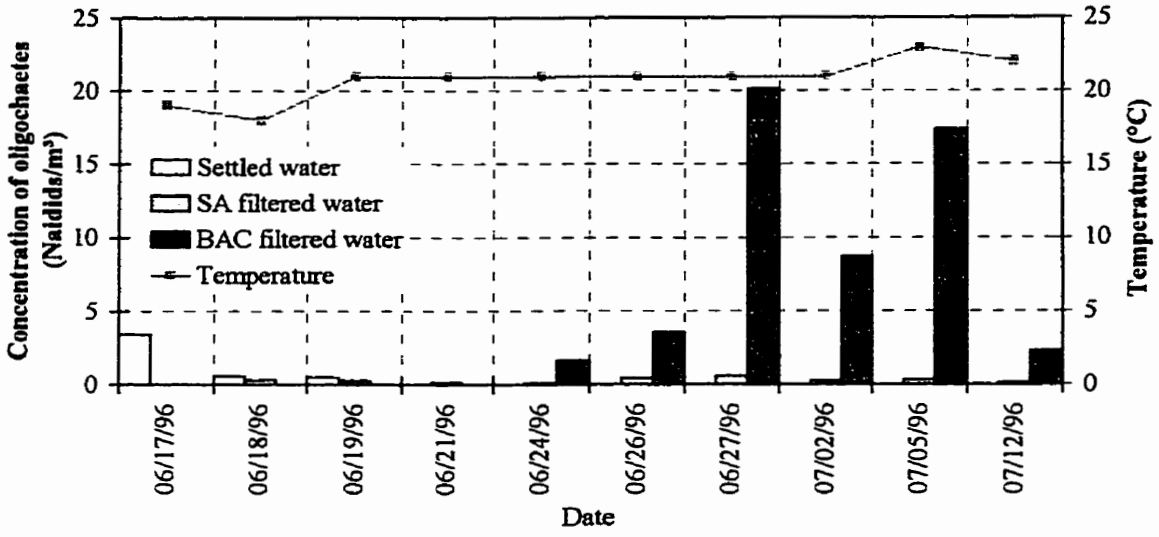

Figure 3.3 Concentration of oligochaetes in the effluent at different locations in the Ste. Rose treatment plant (June and July 1996)

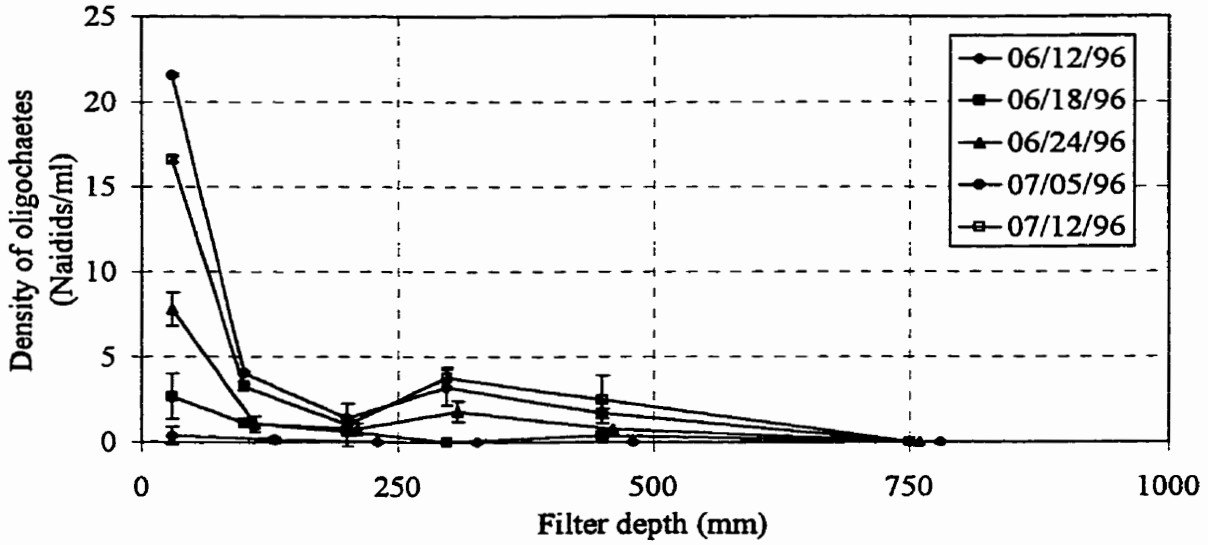

Figure 3.4 Profiles of oligochaete densities during the colonization of BAC filters (June and July 1996) (error bars are standard deviation)

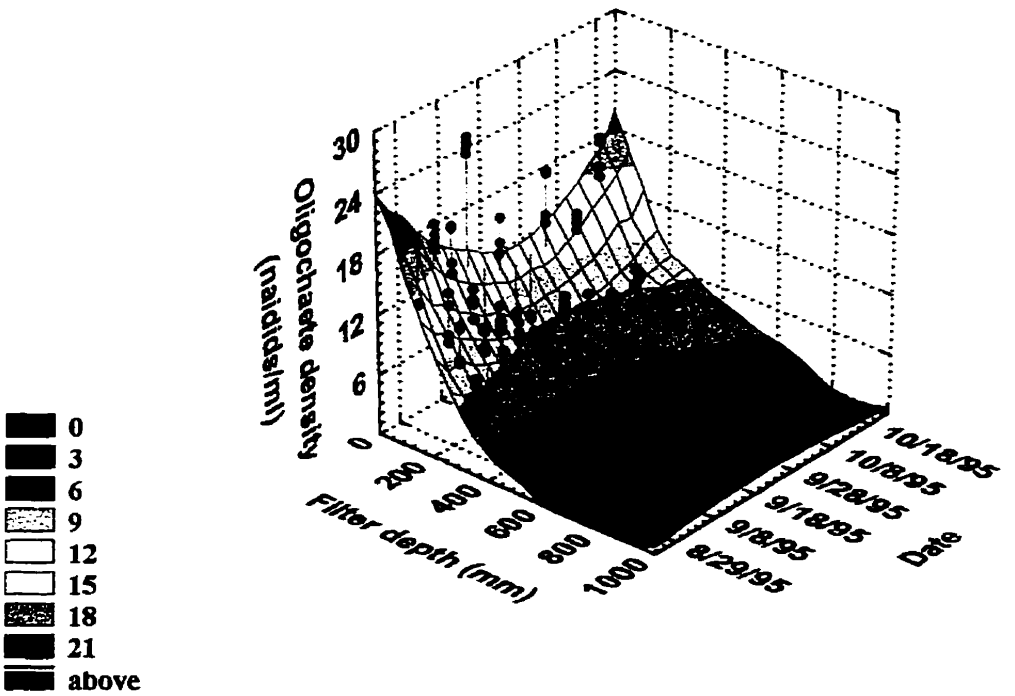

Figure 3.5 Profiles of oligochaete densities in the first 1000-mm filter depth in the BAC filter for temperatures between 23 and 11°C

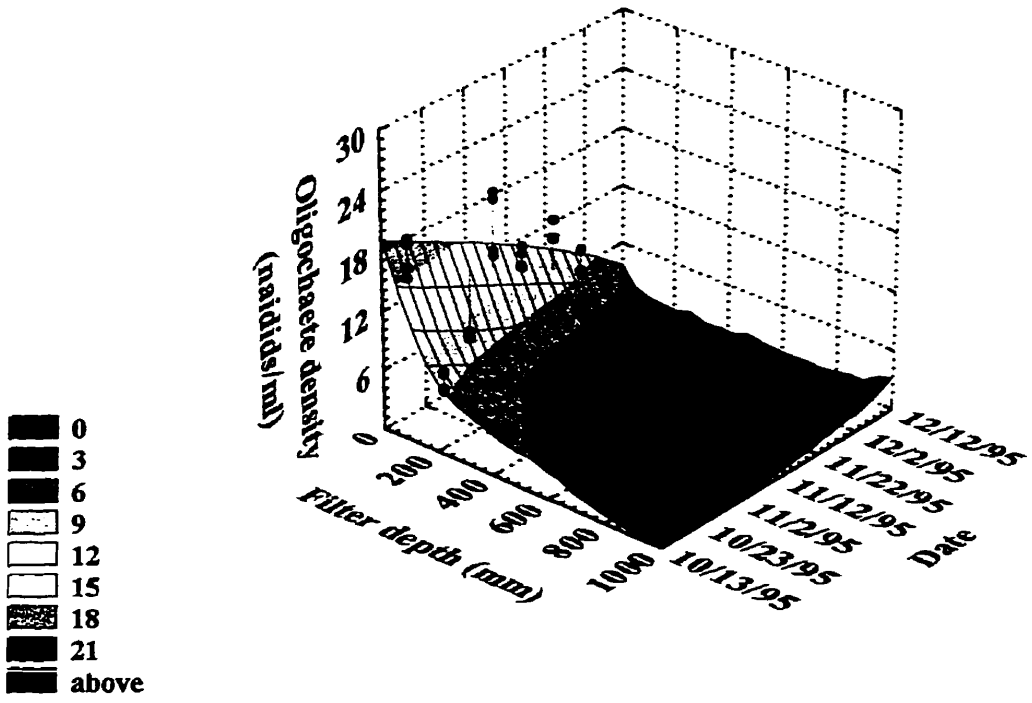

Figure 3.6 Profiles of oligochaete densities in the first 1000-mm filter depth in the BAC filter for temperatures between 11 and 1°C

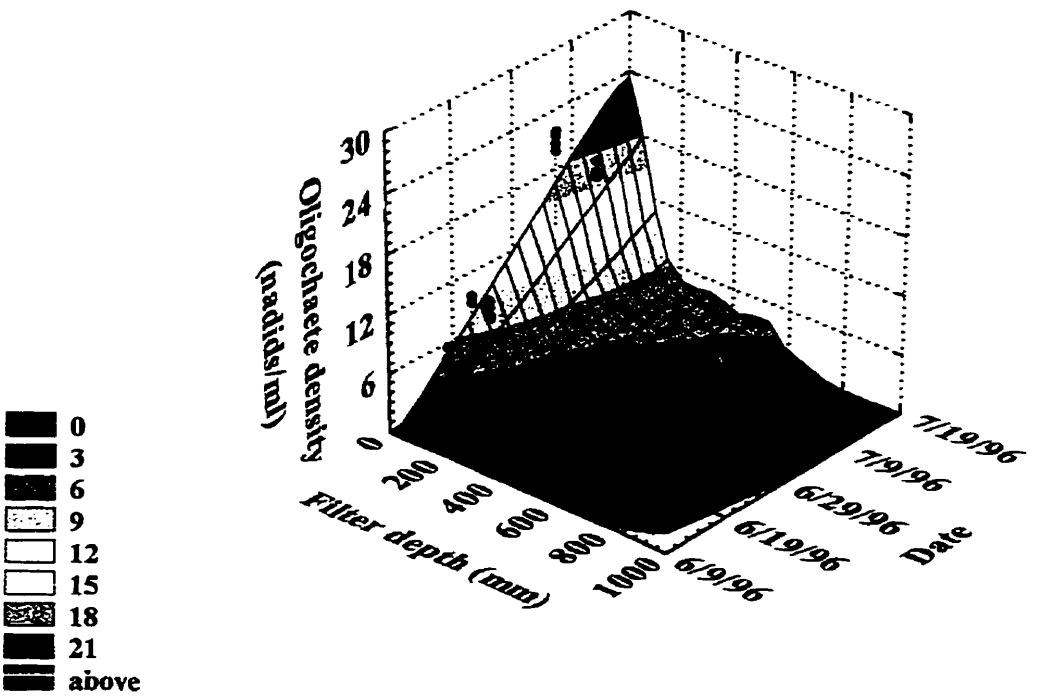

Figure 3.7 Profiles of oligochaete densities in the first 1000-mm filter depth in the BAC filter for temperatures between 18 and 23°C

3.3 CONCLUSION

Ces travaux de recherche ont permis d'identifier les périodes durant lesquelles les oligochètes peuvent être observés en usine. En eaux froides, c'est-à-dire au cours des mois de janvier à mai, les oligochètes ne sont pas détectés dans les filtres CAB (moins de 1 naidid/ml). Au printemps, au cours du mois de juin, lorsque la température de l'eau brute atteint 20°C, les densités d'oligochètes dans les filtres CAB croissent rapidement en surface des filtres pour atteindre une densité d'oligochètes d'environ 20 naïdides/ml. Durant cette période, les oligochètes se reproduisent principalement par reproduction asexuée, ce qui permet à la population de doubler à tous les 4 à 6 jours. La reproduction sexuée des oligochètes durant la même période est cependant possible, nos recherches n'ayant pu prouver le contraire. La population d'oligochètes demeure stable jusqu'à ce que la température de l'eau commence à baisser. Les densités d'oligochètes mesurées en été correspondent aux densités maximales que peuvent supporter les filtres CAB durant la saison chaude, lorsque l'équilibre biologique est atteint. Au mois de décembre, la population d'oligochètes diminue dans les filtres CAB pour atteindre des valeurs de densités d'oligochètes approchant la limite de détection de la méthode. Durant la période froide, les oligochètes assurent probablement la survie de l'espèce au moyen de la reproduction sexuée en formant des cocons.

Dans la filière de traitement d'eau potable, aucun oligochète n'a été détecté à l'eau brute durant la période d'échantillonnage. À la sortie des décanteurs dynamiques à voile de boues, les oligochètes n'ont pu être dénombrés qu'à quelques reprises. Cependant, les concentrations d'oligochètes les plus élevées ont été relevées à l'effluent des filtres CAB (valeurs atteignant 20 naïdides/m^3). Toutefois, on note que des oligochètes ont toujours été observés à l'effluent des filtres SA mais en concentration plus faible, soit inférieur à 1 naïdide/m^3. Enfin, aucun oligochète n'a été détecté à l'effluent des filtres CAB tant que

les densités d'oligochètes dans les filtres CAB n'avaient pas atteint près de 5 naïdides/ml dans les 200 millimètres de la couche supérieure.

Maintenant que les périodes durant lesquelles les oligochètes sont présents en usines sont connus, des mesures de contrôle peuvent maintenant être élaborées et étudiées dans le but de limiter la présence des oligochètes dans les filtres et à l'eau filtrée.

CHAPITRE 4: TECHNIQUE DE CONTRÔLE DES OLIGOCHÈTES EN USINE: LAVAGE DE FILTRE PRÉCÉDÉ D'UN ARRÊT DE FILTRATION

4.1 INTRODUCTION

Étant donné que les périodes durant lesquelles les oligochètes peuvent être détectés en usine ont été identifiées, différentes techniques pour limiter les populations d'oligochètes ont été élaborées. Les recherches ont principalement porté sur des moyens pour limiter les populations d'oligochètes dans les filtres CAB. En limitant la population d'oligochètes dans les filtres CAB, les risques potentiels de retrouver des oligochètes à leur effluent s'en trouvent diminués. L'impact des fréquences des lavages des filtres, des techniques de lavage, de la présence d'une couche de sable sous la couche de charbon actif ont fait l'objet d'essais à l'échelle usine. Certains de ces résultats ont été présentés lors de conférences qui ont eu lieu à Montréal et Boston en 1996. Les résultats présentés portaient sur la comparaison de plusieurs techniques de lavage. Les résumés de ces conférences sont disponibles aux annexes A et B.

Parmi l'ensemble des techniques de contrôle étudiées, une seule technique s'est démarquée. Cette technique consiste à effectuer un arrêt de filtration de quelques heures et ensuite de laver le filtre selon une séquence de lavage bien précise. Utilisée au moment opportun durant l'année, cette technique permet en fait la réduction substantielle de la population d'oligochètes dans les filtres CAB.

La séquence de lavage qui a été développée est le fruit d'observations recueillies auprès des opérateurs de l'usine lors d'arrêts de filtration de filtres CAB. Contrairement à la séquence de lavage classique généralement appliquée dans les usines de traitement d'eau

potable, celle-ci requiert l'introduction d'un lavage à l'eau en début de séquence de lavage. Cette étape du lavage a été ajoutée suite à des observations montrant la migration des oligochètes des filtres CAB vers la tête d'eau surplombant le filtre suite à un arrêt de filtration.

La réduction de la population d'oligochètes dans les filtres par l'application des techniques de contrôle ne peut toutefois se faire au détriment des capacités d'enlèvement par voie biologique des filtres CAB. En effet, la biomasse fixée qui colonise les filtres CAB doit être maintenue en tout temps afin que l'enlèvement du carbone organique dissous et de l'azote ammoniacal puisse se poursuivre.

Les résultats de cette recherche sont présentés sous forme d'article à la section 2.2. L'article a été soumis au *Water Research* en août 1998.

4.2 CONTROLLING OLIGOCHAETES IN BIOLOGICAL ACTIVATED CARBON FILTERS BY A NEW BACKWASHING TECHNIQUE

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ABSTRACT

Drinking water plants and distribution systems throughout the world are frequently populated by invertebrates. Depending on the season, invertebrates can colonize the filters of drinking water treatment plants. Since biological filters support a more substantial biomass than that observed in conventional filters, a trophic chain that includes higher organisms can develop there. Biological filters could therefore provide an environment favourable to the development and maintenance of populations of invertebrates.

Oligochaetes, which are common in surface waters, are often found in the filters of drinking water treatment plants. Biological activated carbon (BAC) filters at the Ste. Rose treatment plant (City of Laval, Québec, Canada) are colonized by oligochaetes belonging to the naidid family during half the year. In order to reduce the population of oligochaetes in biological filters and the presence of oligochaetes in their effluent, a backwashing technique has been developed. This technique involves a 6-hour filter shutdown, followed by backwashing with water at a low flowrate, an air scour and, finally, backwashing with water at a medium flowrate.

The results have shown that a filter shutdown of 6 hours followed by the proposed backwashing technique make it possible to reduce substantially the population of oligochaetes in the filters on more than two filtration cycles of 96 hours each. The oligochaete densities measured at the surface of the filters were 11 naidids/ml prior to the first filter shutdown and fewer than 4 naidids/ml 8 days after the first backwash preceded by a filter shutdown. The results also showed that the fixed biomass was very little affected during filter backwashing preceded by a filter shutdown of 6 hours. The development of anoxic and anaerobic conditions in the filter during the shutdown translated into consumption of the dissolved oxygen and the nitrates by the bacteria, and the formation of ammonia, dissolved organic carbon and nitrites. Anoxic and anaerobic

conditions thus replaced endogenous respiration. The performances of biological removal remained the same following the 6-hour filter shutdown and the proposed backwashing technique as those recorded prior to the shutdown. The reduction in DOC was similar, while the nitrification process became effective once again. The proposed backwashing technique combined with filter shutdown constitutes an effective means of controlling the oligochaete population present in the biological filters, while at the same time preserving the performances of the biological removal of carbon and ammonia during filtration.

INTRODUCTION

Invertebrates are found in most drinking water utilities throughout the world. In the Netherlands, invertebrates have been classified and monitored for several decades now in distribution systems (van Liverloo et van der Kooji 1994). In the United States, studies have shown that invertebrates such as worms and crustacean have been found in a number of drinking water distribution systems (AWWA 1995). In Canada, a recent study investigated the presence of oligochaetes in a drinking water treatment plant (Beaudet et al. 1996). These authors also reported that oligochaetes, which colonize BAC filters in warm waters, are present in the filtered water.

The filters in drinking water treatment plants could constitute a favourable environment for invertebrates. In biological filters, as in conventional filters, there exists a bacterial biomass which is basically a trophic chain which is likely to lead to the development of macro-organisms, the presence of which is incompatible with the demand for water of a high quality. However, the levels of biomass present in biological filters may be much higher (Miltner et al. 1992; Wang et al. 1995), and because the environmental conditions in biomass are favourable to their growth, macro-organisms like nematodes, chironomids and oligochaetes can therefore develop there (Prévost et al. 1991a).

Since a significant population of invertebrates colonizing filters could lead to the presence of invertebrates in drinking water distribution systems, then there is the potential risk that they will appear at the consumer's tap. In 1964, oligochaetes, which were known to be colonizing the sand filters in Rotterdam's drinking water treatment plant in large numbers, were the source of numerous complaints by consumers (Rook 1970).

All kinds of methods have been developed by those in charge of water utilities to control the presence of invertebrates. Classical methods employ chemical, physical and mechanical means to achieve this. Pyrethrin or high concentrations of chlorine are frequently used in contaminated areas to inactivate invertebrates. Another technique consists of the application of a program involving systematic drainage of the distribution system as an active means of control and prevention. At the treatment plant, control measures which are often applied involve increasing the frequency of filter backwashing, or the use of the most effective filter-backwashing techniques, including an air scour and backwashing of the surface of the filters with water (AWWA 1995; Beaudet et al. 1996).

To control oligochaetes in filters, a simple technique which could be used and involves reducing the amount of dissolved oxygen during a filter shutdown. The biomass present in the filters consumes the dissolved oxygen, resulting in the development of anoxic and anaerobic conditions, and, consequently, in the death of the oligochaetes; they are removed by a proper filter backwashing technique following the shutdown. The reduction of the dissolved oxygen is a method that is already used to control zebra mussels in closed systems, but it can take several days or more to complete the process, depending on the rate of consumption of the dissolved oxygen (AWWA 1995). The time required to reach anoxic conditions in the filters depends on the level and the activity of the biomass present.

The impact of shutting down a biological filter has recently been studied by (Niquette et al. 1998b). The results have shown that the oxygen dissolved in BAC filters diminishes rapidly, stabilizing at about 1.5 mg O_2/l two hours after a filter shutdown in warm waters, for densities of fixed biomass close to 18 µg C/ml. The same study has also shown that ammonia, nitrites and dissolved organic carbon (DOC) are produced in stagnant interstitial water during a shutdown. Consequently, backwashing a biological filter following shutdown appears to be necessary, given the significant concentrations of by-products of the shutdown.

Based on the results of previous studies and on the conclusions drawn from them, a new backwashing technique has been developed and tested in a full-scale operation. This new backwashing technique takes into account the most recent works done on filter shutdowns. It is a technique which could also apply in the case of biological filters having problems of a similar nature with other types of higher organisms.

OBJECTIVES

The principal objective of this project was to evaluate the impact of a new backwashing technique on the densities of oligochaetes in BAC filters. The three specific objectives of this study were to: 1) limit the presence of oligochaetes in BAC filters and in their effluent, 2) limit the passage into distribution systems of the by-products of a filter shutdown, 3) maintain the performances of biological removal from the filters at all times.

To achieve these objectives, the following two parameters were studied: 1) oligochaete densities in the BAC filters prior to and following the application of the proposed backwashing technique, 2) oligochaete concentrations in the effluent of the BAC filters prior to and following the application of the proposed backwashing technique. Since the new backwashing technique could not be applied to the detriment of the capacities of biological removal from the BAC filters, other parameters were evaluated as well, namely

fixed biomass, viable and total free bacteria, dissolved oxygen, DOC, ammonia, nitrites and nitrates.

The short- and long-term impacts of the application of the proposed backwashing technique on the oligochaete population in BAC filters, as well as the performances of the biological removal processes, will be discussed.

MATERIAL AND METHODS

The filtration plant

The project was carried out at the Ste. Rose drinking water treatment plant in the (City of Laval, Québec, Canada). The nominal capacity of the plant is 110,000 m^3/d. The filtration plant draws its water from the Mille Iles River, which has high organic load and low alkalinity. The Mille Iles River is fed by the Lake of Deux Montagnes, which is supplied by the Ottawa River in the St. Lawrence Basin. The seasonal characteristics of the raw water are shown in Tableau 2.1. As illustrated in Figure 4.1, the multiple barriers include screening, coagulation-flocculation-settling, filtration on sand and anthracite (10-m/h superficial velocity), ozonation (0.4 mg O_3/l after 10 minutes), filtration on biological activated carbon (10-m/h superficial velocity), disinfection with chlorine dioxide and pH adjustment to 7.3-7.6.

Two filter shutdowns followed by the new filter backwashing technique proposed here were carried out in the same BAC filter on July 8, 1996 and July 16, 1996. Other shutdowns were also carried out in October 1995, December 1995 and May 1996. The proposed backwashing technique, which was tested at full-scale operation, was designed to eliminate oligochaetes migrating from the BAC filter to the water head during the filter shutdown (Tableau 4.2). The filter was shutdown after the level of water head was dropped to 1 meter over the filter media. Six hours after the filter shutdown, a backwash with water at a low flowrate was carried out before air scour in the purpose of evacuating

the oligochaetes present in water head. The use of backwashing with water at a low flowrate is suitable to move naidids present in the water head. By applying a backwashing water at a low flowrate before air scour, the possibility that oligochaetes present into the water head can be re-attached to the filter media grains is reduced.

A conventional backwash including air scour and water backwash only was completed between shutdowns on July 12, 96 and then did not include backwash sequence steps from 1 to 3 presented in Tableau 4.2. The addition of a conventional backwashing between both filter shutdowns was to evaluate the long-term impact of the first shutdown on the population of oligochaetes in the BAC filter.

The BAC filter was backwashed with water disinfected by chlorine dioxide. The frequency of filter backwashing was 96 hours during the experiment. The BAC filter sampled was equipped with a 20-cm sand layer underneath a 180-cm activated carbon in service since 1987. A tracer study using KCl confirmed a water residence time of 45 to 48% of the empty bed contact time (EBCT) in the BAC filter (Niquette et al. 1998b). The superficial filtration rate before shutdown and after filter backwashing was around 5 m/h.

Methods

The method to enumerate oligochaetes in filter media has been described by Beaudet 1998. Oligochaetes found in the treatment plant and enumerated in BAC samples were from the naidid family. A core tube was used to gently extract samples at different depths into the BAC filter. During the filter shutdown, samples were taken every 2 hours from the BAC filter. Figure 4.2 shows the BAC filter depths (FDs) sampled during the study. Media samples were collected in July 1996. The density of the fixed bacterial biomass was determined from the media samples by measuring the potential respiration of radiolabeled glucose (Servais et al. 1991). A saturated solution of ^{14}C glucose (1 mM)

was added to a sample of 2 ml of filter media. After a 3-hour incubation period, the $^{14}CO_2$ produced by the bacteria was collected in an absorbent solution and then detected by means of a Canberra Packard scintillation counter, 1900 Tri-Carb model.

The enumeration of oligochaetes in water sample involved using filtration column in which water was collected and filtered through a 121-µm stainless steel mesh to concetrate oligochaetes (Beaudet 1998). Water samples were collected by using a sampling port located at the BAC filtered water pipe (Figure 2.2). The flow rate of filtered water through the filtration column was measured by means of a graduated cylinder and a chronometer.

Water samples were drained from different depths inside the BAC filter using stainless steel tubing. Water samples were collected in clean glassware (washed with detergent, tap water, solution of 25% hydrochloric acid, demineralized water and ultra-pure water) and analyzed immediately for ammonia, nitrite, nitrate, DOC and free bacteria. The glassware used for de DOC analyzes was muffled at 500°C for 4 hours after cleaning. The vials used for the bacteriological analyzes were cleaned and sterilized. Free bacteria were enumerated by fluorescent microscopy by means of BacLight staining as described by (Barbeau et al. 1997). Concentrations of dissolved oxygen were measured using a Hanna Instruments HI-8543 electronic probe. The probe's precision is estimated ± 0.1 mg O_2/l, but the sampling devices used (tube with one end open to the atmosphere) may favour oxygen dissolution in the sample when the dissolved oxygen concentration is below 2 mg O_2/l. Dissolved organic carbon (DOC) was measured using a Dohrmann DC-180 total carbon analyzer, which uses ultraviolet light promoted persulfate oxidation. Samples was previously filtered through a carbon free borosilicate 0.7-µm filter to remove particulate organic carbon since DOC measured on natural samples filtered through combusted 0.7-µm glass fiber filters was equivalent to DOC measured on samples filtered through 0.45-µm silver or alumina membranes (Kaplan 1994). The

borosilicate filter is known to have a potential for contamination by carbon that is practically nil. Some authors also recommend the use of 0.7-µm borosilicate filter since that particles between 0.2 and 0.7-µm size are not present in any significant amount in surface water (Servais et al. 1995). The DOC measurement precision was estimated to ± 0.05 mg C/l. Ammonia concentrations were evaluated using the indophenol colorimetric method (AFNOR 1990). The basis for this method is that ammonia, in alkaline solutions, reacts with chlorine and phenol to produce blue complex. Ammonia concentrations are quantified using spectrophotometric measurements (wavelength of 640 nm) of the treated samples and standard solutions. The precision of the method is evaluated to ± 3 µg/l at low ammonia concentration (concentration > 5µg/l). Nitrate and nitrite concentrations were measured using a Dionex DX-300 ionic chromatography. An Ionpac AS-11 analytic column protected by an Ionpac Ag-11 column held inorganic anions and organic acids. NaOH solutions were used as eluent. Detection was made by a Dionex CDM-2 conductivity detector. Analytical precision ranged from 0.0002 to 0.02 mg/l depending on the anion measured.

Statistical analyses were computed with Statistica 5.1, version 97, for Windows 95 from Statsoft Inc. on a Pentium PC computer. Since sampling filter depths changed slightly from a sampling to another, they have been associated to 100-mm filter depth ranges (FD1= 0-100 mm; FD2= 100-200 mm; FD3= 200-300 mm; FD4= 300-400 mm; FD7=600-700 mm) to perform statistical analysis. A significance level (α) of 5% was used for all tests.

RESULTS

Variations in oligochaete density, fixed biomass and free bacteria following a filter shutdown of 6 hours and backwashing

Oligochaetes

The results have shown that a filter shutdown followed by backwashing affects the oligochaete densities measured in the BAC filter studied. On July 8, 1996, the highest oligochaete densities, 11±2 naidids/ml, were recorded on the surface of the filter prior to the shutdown (Figure 3.3a). Deeper within the filter, the oligochaete densities were lower, 1±1 naidid/ml or fewer. These results are analogous to those reported by (Beaudet 1998), which showed higher oligochaete densities on the surface of BAC filters than at deeper levels. Following the filter shutdown, the oligochaete densities were substantially reduced, as shown in Figure 3.3a. Six hours after the shutdown, the oligochaete densities on the surface of the BAC filter dropped to a value of 1±1 naidid/ml. This reduction in the oligochaete population was statistically significant 6 hours after the shutdown, as indicated in Tableau 4.3a. However, at the deepest level studied (FD7), no significant difference was recorded (Tableau 4.3a).

The reduction in the oligochaete population in the filter is the result of a migration of the oligochaetes present in the filter medium towards the water head overhanging the filter. The concentration of oligochaetes in the surface water 6 hours after the shutdown was evaluated at 75,000 naidids/m^3. With the application of backwashing with water at a low flow rate prior to air scouring, the majority of the oligochaetes present in the water head during the shutdown were rinsed out in the wash water.

The oligochaete densities in the filter measured 30 minutes after the end of the backwashing remained at levels observed 6 hours after the shutdown, but were significantly different from those measured prior to the shutdown (Tableau 4.3a). After

the filter has been restarted, some of the oligochaetes, which had not been removed during the backwashing, were found in the effluent of the BAC filter, at concentrations as high as 160 naidids/m^3 in the first 20 minutes after the filter had been restarted. However, the concentration of oligochaetes in the effluent measured over the 96 hours following the shutdown reached only 0.1 naidid/m^3.

After the first filter shutdown, conventional backwashing was applied 96 hours later, on July 12, 1996. This backwashing was not preceded by a filter shutdown in order to evaluate the long-term impact of the first filter shutdown followed by the backwashing technique.

The same BAC filter was shut down for a second time, on July 16, 1996. The results showed that in this case the oligochaete densities at the surface of the BAC filter prior to the shutdown were lower than those observed on July 8, 1998 (Figure 3.3a and 3.3b). The impact of this second filter shutdown on the oligochaete densities was therefore not as significant as the first, since the oligochaete densities throughout the filter had been lower prior to the shutdown (Figure 3.3b). Tableau 4.3b, which presents the statistical analyses, indicates no significant difference in the oligochaete densities 6 hours after the shutdown, except in the case of the sample taken at the surface, and no significant difference in the oligochaete densities 30 minutes after backwashing at 3 of the 5 depths sampled. The oligochaete concentration in the effluent of the BAC filters was null 20 minutes after the filter had been backwashed: no oligochaetes were counted.

Fixed biomass

The fixed biomass in the BAC filter was not very much affected by the shutdown executed on July 8, 1996 (Figure 4.4a). The statistical analyses do not show any significant difference at a confidence level of 5% between the densities of fixed biomass

prior to the shutdown, 6 hours after the shutdown and 30 minutes after the filter has been restarted (Tableau 4.4a).

For the second filter shutdown followed by backwashing, the densities of fixed biomass on the surface of the BAC filter were higher that those measured prior to the shutdown of July 8, 1996 (Figure 4.4a and 4.4b). The densities of fixed biomass varied between 19 and 22 µg C/ml - a mean of 20.5 µg C/ml - on July 16, compared to 15.7 µg C/ml on July 8. However, no significant difference in the densities of fixed biomass were observed 6 hours after the filter shutdown or 30 minutes after the filter restart, compared with those measured prior to the filter shutdown (Tableau 4.4b).

During the period of the study, the levels of fixed biomass at the surface of the filter increased by 23% between July 8 and July 16, 1996. This increase is probably attributable either to the seasonal rise in temperature and to the changes in the characteristics of the raw water during the test period or either to the absent of predator of bacteria in the BAC filter. For all the biomass analyses performed during the study, the fixed biomass density results are comparable to those obtained in other similar studies in which the same measurement method was used (Niquette et al. 1998a; Servais et al. 1991).

Free bacteria

The measurements of viable free bacteria taken prior to the filter shutdown of July 8, 1996 showed an increase in the concentration of viable free bacteria as the affluent crossed the BAC filter. Similar results were obtained on July 16, 1996 but are not presented. In fact, the concentration of viable free bacteria at the inflow of the BAC filter, which had been 1.3×10^4 bacteria/ml, grew to 5.4×10^4 bacteria/ml at the outflow (Figure 4.5a). Simultaneously, the concentration of total free bacteria in the affluent of the BAC filter increased from 2.5×10^4 to 1.9×10^5 bacteria/ml in the effluent (Figure 4.5a).

These results are comparable to the results of other studies which show a net export of biomass when measured by counting on agar (Prévost 1991; Prévost et al. 1991a; Servais, 1991). However, other studies have indicated that there is a quasi-null export of bacteria when epifluorescence methods are used to determine total counts (Prévost et al. 1991b).

During the shutdown of July 8, 1996, the concentrations of free bacteria increased in the interstitial water of the filter, suggesting that bacteria became detached from grains of activated carbon. The highest concentrations of free bacteria were observed 6 hours after the shutdown: the total free bacteria therefore increased by one Log, or from $8.0x10^4$ to $6.7x10^5$ bacteria/ml, in the interstitial water at FD2. Filamentous bacteria, which had been retained on the grains of the filter medium during filtration, were also observed 6 hours after the shutdown in the stagnant interstitial water. The viable free bacteria followed the same tendency, going from $5.3x10^5$ to $5.2x10^5$ bacteria/ml at FD2. The fraction of viable free bacteria was high, close to 77% of all the total free bacteria. Following the shutdown and backwashing of the filter, the number of total free bacteria in the effluent was found to be higher by 0.6 log than prior to the filter shutdown, or $7.4x10^5$ bacteria/ml, compared with $1.9x10^5$ bacteria/ml before the shutdown (Figure 4.5b). Viable free BAC bacteria were also exported to the effluent of the BAC filter in similar proportions, $2.20x10^5$ bacteria/ml compared to $5.44x10^4$ before shutdown (Figure 4.5a).

Variation in the quality of the stagnant water and the filtered water following a filter shutdown of 6 hours and backwashing

The quality of the water and the conditions that prevailed in the BAC filter prior to the shutdown changed considerably during the filter shutdowns of July 8 and July 16, 1996. The concentrations of dissolved oxygen diminished rapidly a few hours after the shutdowns, dropping from 12 mg/l to less than 4 mg O_2/l at the surface of the filter

(Figure 4.6). At the moment when the concentrations of dissolved oxygen were below to 4 mg O_2/l, the nitrate concentrations began to drop and were completely exhausted by the bacteria, in the interstitial water of the surface layer of the filter, 4 hours after the shutdown (Figure 4.7a and 4.7b). The production of nitrites was also observed during the same period in the interstitial water of the surface layer of the filter (Figure 4.8a and 4.8b). The concentrations of ammonia in the BAC filter increased continually, reaching maximal values of 0.160 mg N/l (Figure 4.9a and 4.9b). The DOC concentrations also increased during the shutdown, reaching as much as 3.3 mg C/l on July 16, 1996 in the interstitial water of the surface layer of the BAC filter (Figure 4.10).

The biological performances of the BAC filter 30 minutes after the filtration restart were almost the same as those observed prior to the shutdown. No significant rise in DOC, nitrates or ammonia was observed in the effluent of the BAC filter after the restart. In fact, the high concentrations of ammonia and DOC in the stagnant water following the shutdown were eliminated by the filter backwashing. Moreover, the nitrification and the removal of the DOC by the bacteria were re-established 30 minutes after the backwashing (Figure 4.9 and 4.10). The difference in reduction in dissolved oxygen concentrations observed between the affluent and the effluent following the restart of the filter confirms that there exists sustained bacterial activity there (Figure 4.6). Finally, the concentrations of ammonia were approximately 0.04 μg N/l in the effluent of the BAC filter and not measurable in the filter's effluent before shutdown and after restart (Figure 4.9). The reduction in DOC in the BAC filter was 0.6 mg C/l prior to the filter shutdown, in comparison with 0.5 mg C/l following the backwashing on July 16, 1996 (Figure 4.10).

DISCUSSION

Evolution of the biomass and of the quality of the stagnant water during a shutdown

Oligochaetes

The evolution of the oligochaete density profiles presented in Figures 3a and 3b clearly indicate a reduction in the population of oligochaetes in the BAC filters following a filter shutdown. The density profiles during the shutdown of July 8, 1996 show a substantial reduction in the population of naidids in the BAC filter following the shutdown, which can be observed mainly at the surface (Figure 3.3a). The results presented in Figure 3.3a also indicate that 4 hours after the shutdown the oligochaete population had already been greatly reduced.

By contrast, during the second filter shutdown, executed on July 16, 1996, this reduction is not very significant (Figure 3.3b), given that on July 8, 1996 the oligochaete population had been sharply reduced following the first filter shutdown (Figure 3.3a, 30 minutes after the backwashing). The impact of the filter shutdown on July 8 was became perceptible after more than 2 filtration cycles of 96 hours. Indeed, the oligochaete densities measured on July 16, 1996 prior to the second shutdown remained at levels below 4±1 naidids/ml at the surface of the BAC filter (Figure 3.3b). The rise in oligochaete densities recorded at the surface of the filter between the two filter shutdowns is probably attributable to the asexual mode of reproduction of oligochaetes, which makes it possible for the naidid population to double in the space of 4 to 6 days when the temperature reaches 20°C in the BAC filters in suitable conditions of development (Beaudet 1998).

The reduction in the oligochaete population observed in the BAC filters following the filter shutdown results in a migration of the naidids present in the filter media towards the water head overhanging the filter. The presence of naidids in the water head was

observed throughout the period of the two shutdowns, 2 hours after each shutdown, although much less so after the second. This migration is apparently caused by the lack of dissolved oxygen in the stagnant interstitial water in the filter. The reduction in the concentration of dissolved oxygen is caused by the metabolism of the biological communities present in the filter. Given that the respiration of oligochaetes takes place through the body wall (Brinkhurst et Gelder 1991; Stephenson 1930), the absence of dissolved oxygen in the filter probably favours the migration of oligochaetes towards an environment with higher dissolved oxygen concentrations, the water head overhanging the filter. This lack of dissolved oxygen doubtless affected the oligochaetes which were, while they were being discharged in the wash water following the filter shutdown, became inert, or possibly died. Finally, it is also probable that other by-products produced during the filter shutdown, such as nitrites or ammonia had stressed the naidids.

The reduction in the naidid population in the BAC filters made possible the reduction, or even prevention, of the presence of oligochaetes in the filtered BAC effluent. With the exception of the first 20 minutes following the first backwashing preceding a filter shutdown, the concentration of oligochaetes in the effluent of the BAC filter was reduced substantially, to fewer than 0.1 naidids/m^3. This concentration is ten to twenty times lower than that measured when BAC filters are cleaned by a conventional backwashing (unpublished data).

Development of anoxic and anaerobic conditions

When the concentrations of dissolved oxygen become insufficient for bacterial respiration following a filter shutdown, anoxic and anaerobic conditions develop in the BAC filter. Nitrates are then used as electron acceptors by facultative and aerobic heterotrophic bacteria less than 2 hours after the shutdown. A reduction in the concentrations of nitrates is then observed (Figure 4.7). Two nitrate dissimilation processes predominate in the hours following the shutdown: denitrification by respiration ($NO_3^- \rightarrow NO_2^- \rightarrow N_2O \rightarrow$

N_2) and the reduction of nitrates by dissimilation into ammonia ($NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+$). These two processes are only triggered if the concentrations of dissolved oxygen are low; they therefore account for 70 to 75% of the total removal of nitrates (Benefield et Randall 1980). There is a third nitrate reduction process, which consists in reducing nitrates through assimilation ($NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+$ and organic nitrogen). This process could also occur in the BAC filters, but the results are quantitatively negligible and it may even be inhibited in environments having high concentrations of ammonia (1mM) and organic nitrogen (Tiedje 1985).

The transformation of nitrates into nitrites was observed during both shutdowns. The rate of transformation of NO_3^- into NO_2^- was more rapid than the rate of transformation of NO_2^- into NO_2, into N_2 and into ammonia, since the NO_2^- was measured in the stagnant interstitial water (Figure 4.8). Moreover, numerous studies have shown analogous accumulations of intermediate by-products during the denitrification process due to inhibitions of all kinds (Niquette et al. 1996; Tiedje 1985).

The transformation of nitrates into nitrites is accompanied by the production of energy in the majority of micro-organisms, unlike the transformation of nitrites into gaseous products or into ammonia which requires energy. The lack of energy in the transformation of nitrites into nitrogen probably explains the accumulation of nitrites in conditions where there is limited carbon (Tiedje 1985). A number of types of bacteria, among them *Campylobacter sputorum, Desulfovibrio gigas, Wollinella succinogenes* and *E. coli*, can, however, produce adenosine triphosphate (ATP) by combining oxidation of formate or H_2 to nitrites reduction to NH_4^+ (Motteram et al. 1981). However, this pathway would represent the conversion of only 20% of the nitrates into ammonia at the time of denitrification by *E. coli*. On the surface of BAC filters, the transformation of nitrites into ammonia during filter shutdown represents at most 24 to 30% of the total conversion of the nitrites, supposing the bacterial lysis to be negligible. Consequently,

the proportion of nitrites transformed into gaseous nitrogen would be more than 70%. These percentages were calculated based on variations in nitrites and ammonia between 2 and 4 hours after the two filter shutdowns (Tableau 4.5). However, since the production of ammonia occurs even after the nitrites have been exhausted, then bacterial lysis during filter shutdown should be considered possible.

The use of nitrates by micro-organisms should favour the organisms responsible for the dissimilation of nitrates into ammonia under continuous anoxic conditions, and denitrifying bacteria when anoxic conditions are only temporary (Tiedje 1985). So, when BAC filters are operated in aerobic conditions, the maintenance of a population of denitrifying bacteria should be favoured.

The rate of formation of ammonia during a filter shutdown is a function of the densities of the fixed bacteria in the filter. At 22°C, the rate of formation of ammonia per mg of fixed biomass expressed in carbon varied between $1.1x10^{-2}$ and $1.6x10^{-2}$ mg NH_4^+-N/mgC•h once anaerobic conditions have become well established. The highest rates of transformation were found at the surface of the filter where the biomass densities were the highest.

Oligochaetes cannot be considered responsible for the rise in ammonia observed during filter shutdown, even though their metabolism produces nitrogenous waste products (Arms et Camp 1987). A filter shutdown executed on May 29, 1996, showed similar increases in ammonia in the absence of oligochaetes (unpublished data).

A derivation of the Michaelis-Meten model proposed by (Bethlach et Tiedje 1981) introduces a factor P which varies between 0 and 100% to take into account the degree of inhibition of the enzymatic kinetics during denitrification (equation 4.1):

$$r = p\frac{R_{max}S}{K_m + S} \qquad \text{(Equation 4.1)}$$

where r = reaction rate

R_{max} = maximum rate of enzyme formation

K_m = half-saturation constant= $R_{max}/2$

S = substrate concentration

p = inhibition factor = 0 % < p < 100 %

This inhibition factor brings into play: 1) dissolved oxygen, which acts as an electron acceptor and favours the inactivation of certain enzymes, 2) carbon, the presence of which is essential as an electron donor, 3) certain environmental factors, like pH, temperature and the presence of chemical toxins. In the case of a BAC filter that is shut down, oxygen should not inhibit the rates of transformation of nitrites into gaseous nitrogen or into ammonia since the dissolved oxygen was no longer accessible to the bacteria 2 hours after the shutdown. As mentioned previously, the accumulation of nitrites in the stagnant interstitial water is probably caused by a lack of electron donors, such as a source of carbon which is easily assimilated by bacteria. The lack of accessibility of easily assimilated carbon, especially in acid or alcohol form, could then generate an accumulation of nitrites and cause the process of transformation of nitrites into N_2 and into NO_2 to slow down.

Bacterial lysis

The development of anoxic and anaerobic conditions is responsible for the bacterial lysis of a part of the fixed biomass during filter shutdown and of the salting out of intracellular constituents such as organic carbon and ammonia. Under anoxic conditions, more fermentation products are formed and the bacteria excrete larger amounts of carbon in the absence of oxygen; the limitation of bacterial activity by carbon during denitrification then becomes less probable, except if the easily assimilated carbon is present in a

sufficiently limiting concentration to slow down the enzymatic processes in the presence of a large population of bacteria (Tiedje 1985). This is undoubtedly what occurs during the first hours following the filter shutdown: the readily biodegradable DOC present in the water is first consumed by the bacteria, but, after it has been exhausted completely, the DOC required for continued cellular respiration comes from bacterial lysis. The lysis of a portion of the bacterial flora thus appears progressively, probably once the concentration of dissolved oxygen reaches 4 mg O_2/l or less. Acting as a donor of electrons, the readily biodegradable DOC produced during lysis is then immediately consumed by the facultative aerobic bacteria until the supply of nitrates has been completely exhausted. The rise in DOC observed after 2 hours probably results from DOC that is not readily assimilated by bacteria and is released during lysis (Figure 4.10). The increase in total nitrogen (NO_3^-, NO_2^- and NH_4^+) 2 hours after the shutdown, and more particularly in ammonia when the nitrates and nitrites have been completely exhausted, confirms the hypothesis that bacterial lysis actually exists (Tableau 4.5a). When the dissolved oxygen and the nitrates have been completely consumed, endogenous respiration replaces the anoxic and anaerobic conditions.

Detachment of bacteria from filter media

Filter shutdown favours the breaking away of bacteria from the filter media. In fact, the measurement of viable and total free bacteria indicates increases of 0.99 and 0.92 log respectively in stagnant interstitial water (Figure 4.5). A large percentage, or 77%, of the total free bacteria were viable. A recent study has shown that biofilms of mixed bacterial communities and of individual species can develop on solid surfaces exposed to a continuous flow of nutrients by means of biological mechanisms (Davies et al. 1998). The opposite mechanisms, of attachment of bacteria, could be possibly the cause of bacteria breaking away from the carbon grains, although the detachment of bacteria following the elimination of shear forces during the filter shutdown cannot be excluded.

The detachment of bacteria from filter media also could be due to variations in nutrient supply, as studied by Sawyer et Hermanowicz (1998).

Biological performances prior to the shutdown and after the restart

Figures 9 and 10 show the reduction in ammonia and DOC in the BAC filters during filtration prior to and after the shutdown on July 16, 1997. As indicated in Figure 4.9 and 4.10, the reduction in ammonia and DOC occurs principally at the surface of the BAC filter, where the densities of fixed biomass are higher. These results are similar to those obtained in other studies which show the removal of DOC and ammonia from BAC filters at the surface layer of the filter media (Niquette et al. 1998b; Servais et al. 1991). The presence of nitrites in the effluent of BAC filters was negligible (Figure 4.8).

The backwashing method used seemed to limit the presence of the by-products of filter shutdown in the effluent of the BAC filter. Indeed, no significant rise in DOC, in nitrates or in ammonia was observed in the effluent of the BAC filter after it had been restarted.

CONCLUSION

In the light of the results obtained, the proposed backwashing technique, which consists in executing a 6-hour filter shutdown prior to backwashing the filter, makes it possible to eliminate substantially the population of oligochaetes present in the biological filter. After two filtration cycles of 96 hours, the oligochaete population had not reached the level recorded prior to the shutdown. Based on the results obtained, a filter shutdown close to 6 hours, in the order of 4 hours, could reduce the population of oligochaetes in BAC filters. During the shutdown preceding backwashing and 30 minutes after the filter backwashing, the fixed biomass remained constant, even though the lysis of a portion of the bacterial flora is responsible for an increase in the ammonia and DOC 6 hours after the filter shutdown.

Moreover, the use of the proposed backwashing technique to remove the oligochaetes present in the filters does not affect the biological removal capacities of the DOC and the ammonia nitrogen from the filter 30 minutes after restarting the filter. However, given the significant production of by-products in a filter shutdown, it becomes essential to backwash a filter which has been through a shutdown, even if the shutdown lasts only a few hours.

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Tableau 4.1 Ranges of physico-chimical and bacteriological parameter values for the Ste. Rose raw water from the Mille-Iles River (Laval, Québec, Canada)

Parameters	Seasons			
	Spring	Summer	Autumn	Winter
Temperature (°C)	0.3-25.4	15.9-28.0	0.4-18.2	0.1-0.3
PH	7.0-7.6	6.7-8.1	7.1-7.6	7.0-7.5
Turbidity (NTU)	2.0-56.0	2.0-12.2	2.8-75.0	2.0-8.9
Color (ACU)	41-328	28-91	40-328	41-85
Alkalinity (mg $CaCO_3$/l)	20-47	23-38	19-39	20-45
Hardness (mg $CaCO_3$/l)	28-64	30-51	31-59	26-67
TOC (mg C/l)	5.5-6.9	5.8-7.1	5.8-8.3	5.5-7.8
DOC (mg C/l)	5.4-6.9	5.3	6.4-7.2	5.4-6.9
BDOC (mg C/l)	0.3-0.7	0.7	0.7	0.1-0.4
HPC/100 ml	1,000,000			
Total Coliforms (CFU/100 ml)	1,000- 20,000			

*Source : City of Laval (1987-1995), Dubreuil 1996

Tableau 4.2 Sequence of backwashing technique for a filter shutdown followed by backwash with water at a low flowrate, and then air scour and backwash with water at a medium flowrate

BACKWASH SEQUENCE	Backwash Rate (m/h)	Duration (min)
1- Decreasing of level water in BAC filter to 1 m	--	--
2- Filter shutdown	--	360 (6 hours)
3- Backwash with water at a low flowrate	30-35	5
4- Air scour	20-25	2
5- Backwash with water at a medium flowrate	40-45	16
6- Waste filtration	10	5

Tableau 4.3 Statistical analysis of oligochete densities 6 hours after shutdown and 30 minutes after restart a) on July 8, 1996 and b) on July 16, 1996

a)

	6 hours after shutdown		30 min after backwash	
Sample location	P-level	Significant Difference	P-level	Significant Difference
FD1	**0,003**	**Yes**	**0,000**	**Yes**
FD2	**0,004**	**Yes**	**0,001**	**Yes**
FD3	**0,005**	**Yes**	**0,014**	**Yes**
FD4	**0,014**	**Yes**	**0,041**	**Yes**
FD7	1,000	No	0,182	No

b)

	6 hours after shutdown		30 min after backwash	
Sample location	P-level	Significant Difference	P-level	Significant Difference
FD1	**0,037**	**Yes**	0,077	No
FD2	0,391	No	**0,014**	**Yes**
FD3	1,000	No	1,000	No
FD4	0,604	No	**0,014**	**Yes**
FD7	0,182	No	0,182	No

Tableau 4.4 Statistical analysis of densities of fixed biomass 6 hours after shutdown and 30 minutes after restart a) on July 8, 1996 and b) on July 16, 1996

a)

	6 hours after shutdown		30 min after backwash	
Sample location	P-level	Significant Difference	P-level	Significant Difference
FD1	0,371	No	0,194	No
FD2	0,262	No	0,127	No
FD3	0,241	No	0,199	No

b)

	6 hours after shutdown		30 min after backwash	
Sample location	P-level	Significant Difference	P-level	Significant Difference
FD1	0,145	No	0,104	No
FD2	0,823	No	0,742	No
FD3	0,562	No	0,816	No

Tableau 4.5 Total nitrogen during the filter shutdown at the surface (FD1) of the BAC filter a) on July 8, 1996 and b) on July 16, 1996

a)

	NO_3^- (mg N/l)	NO_2^- (mg N/l)	NH_4^+ (mg N/l)	Total (mg N/l)
0h after shutdown	0,345	0,000	0,000	0,345
2h after shutdown	0,063	0,263	0,045	0,371
4h after shutdown	0,009	0,010	0,107	0,126
6h after shutdown	0,004	0,000	0,154	0,158
30 min after restart	0,345	0,000	0,002	0,288

b)

	NO_3^- (mg N/l)	NO_2^- (mg N/l)	NH_4^+ (mg N/l)	total (mg N/l)
0h after shutdown	0,344	0,000	0,000	0,344
2h after shutdown	0,116	0,235	0,029	0,380
4h after shutdown	0,009	0,064	0,079	0,152
6h after shutdown	0,000	0,007	0,126	0,133
30 min after restart	0,355	0,000	0,000	0,355

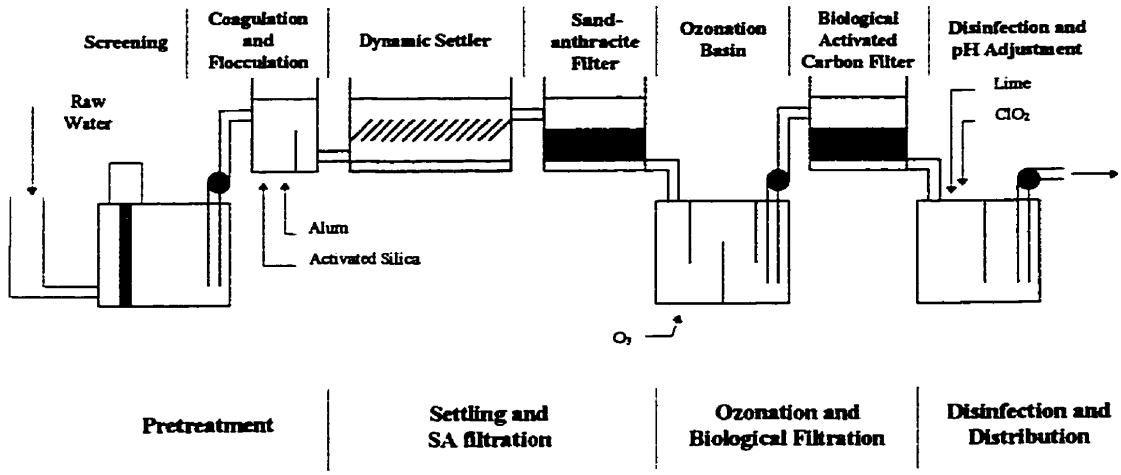


Figure 4.1 Schematic flow diagram of the St. Rose filtration plant

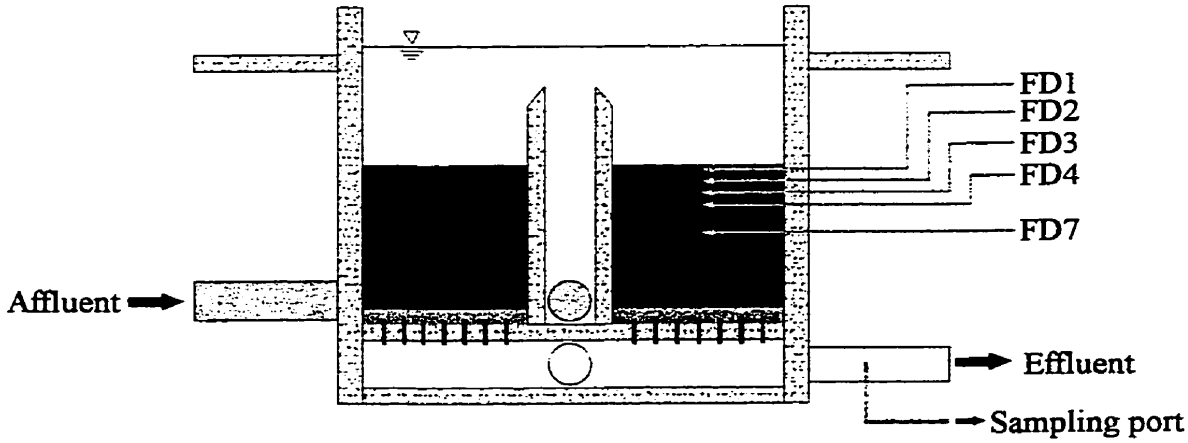
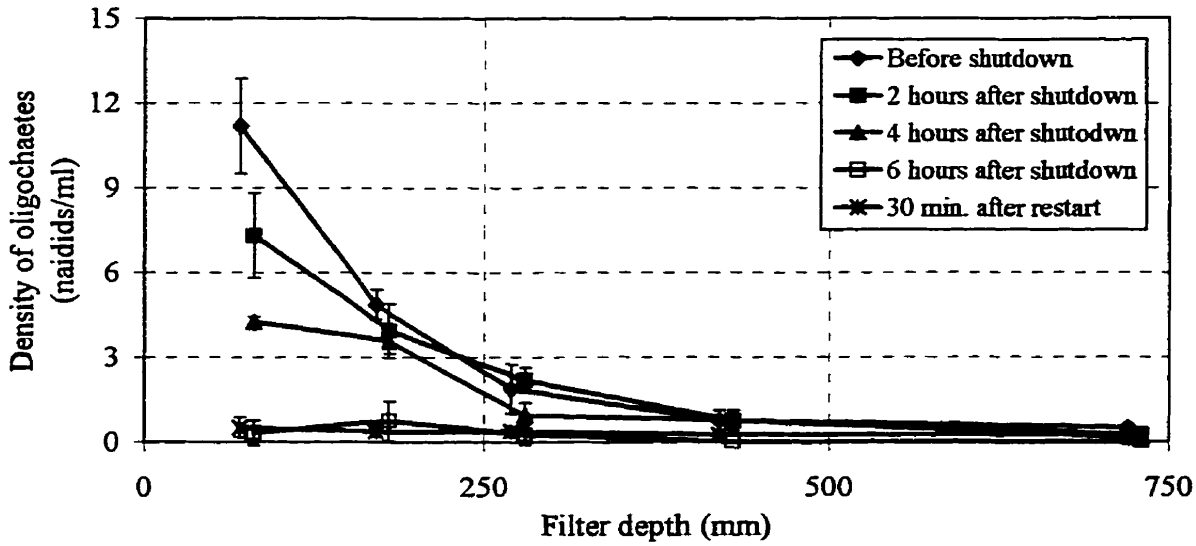


Figure 4.2 Liquid and solid sampling locations in the BAC filter

a)



b)

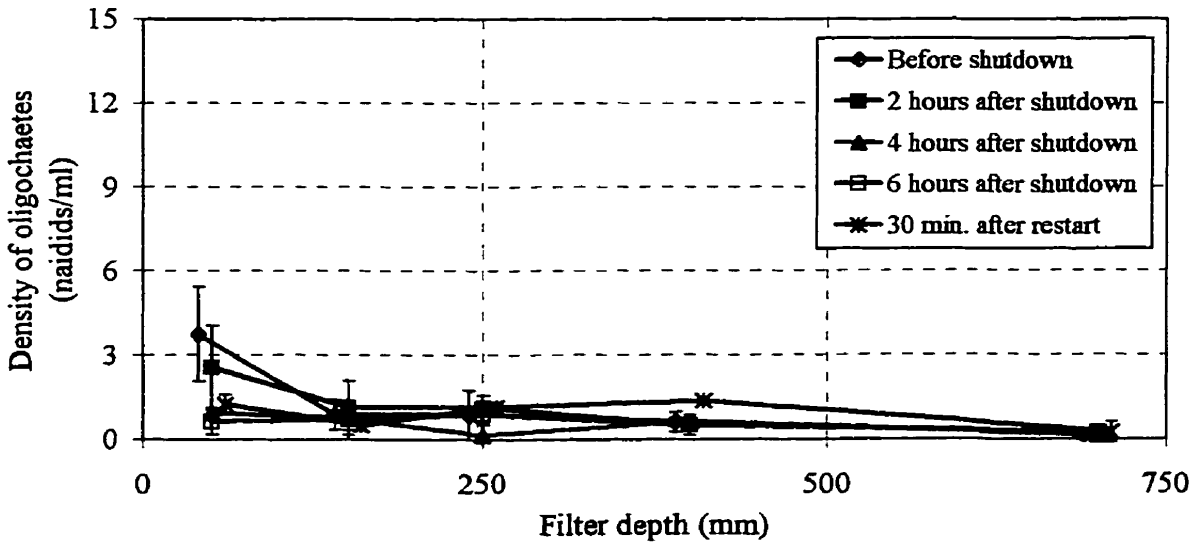
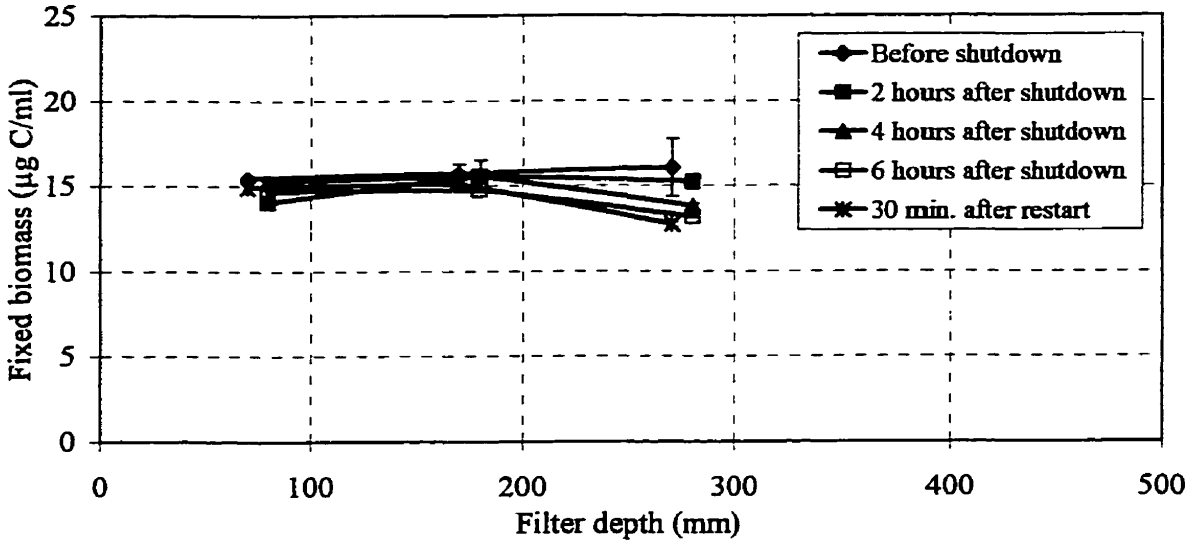


Figure 4.3 Evolution of profiles of oligochaete densities in BAC filter a) on July 8, 1996 (T=22°C) and b) on July 16, 1996 (T=23°C) before and after a 6-hour filter shutdown

a)



b)

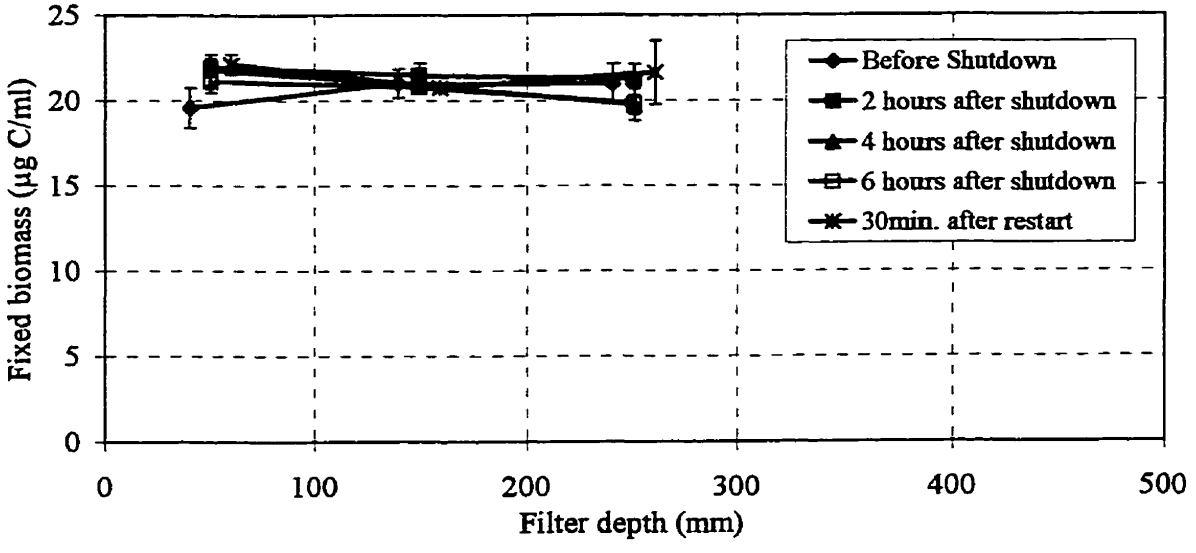
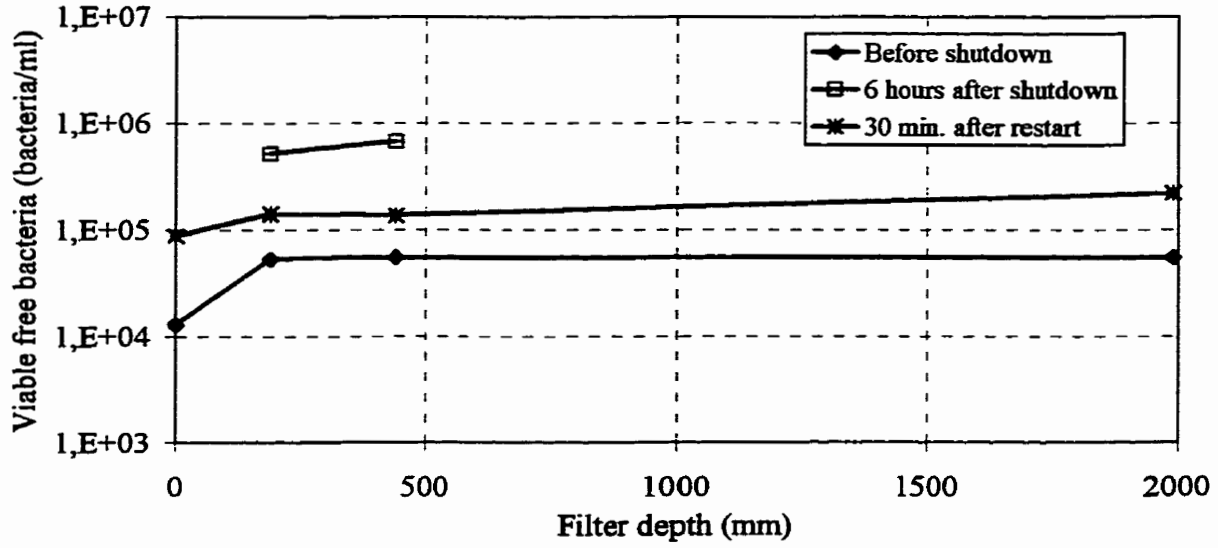


Figure 4.4 Evolution of profiles of fixed biomass densities in BAC filter a) on July 8, 1996 (T=22°C) and b) on July 16, 1996 (T=23°C) before and after a 6-hour filter shutdown

a)



b)

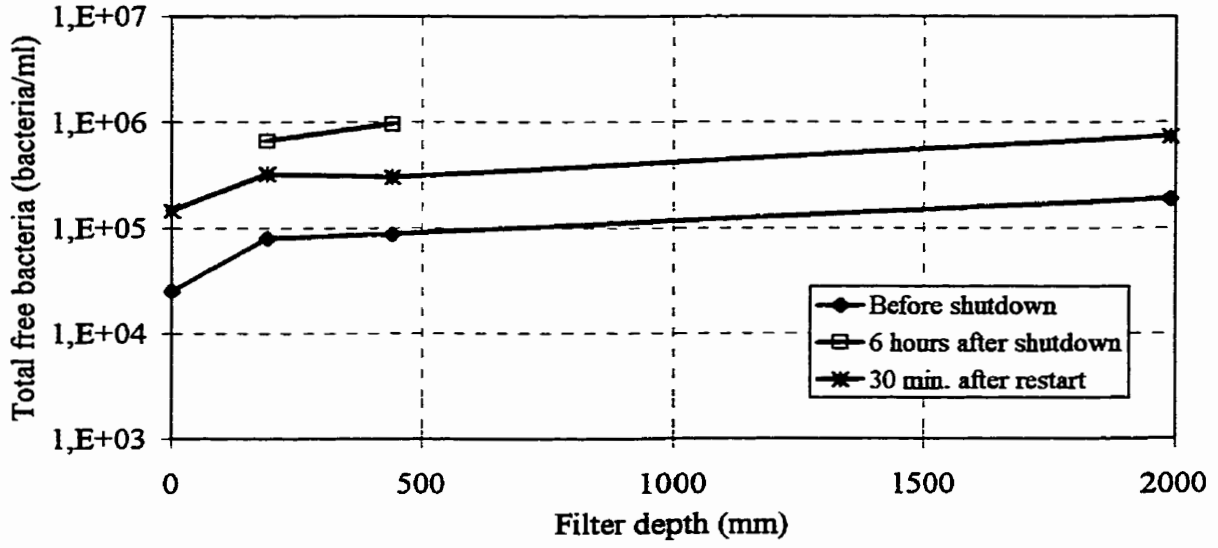


Figure 4.5 Evolution of profiles of a) viable and b) total free bacteria in the BAC filter on July 8, 1996

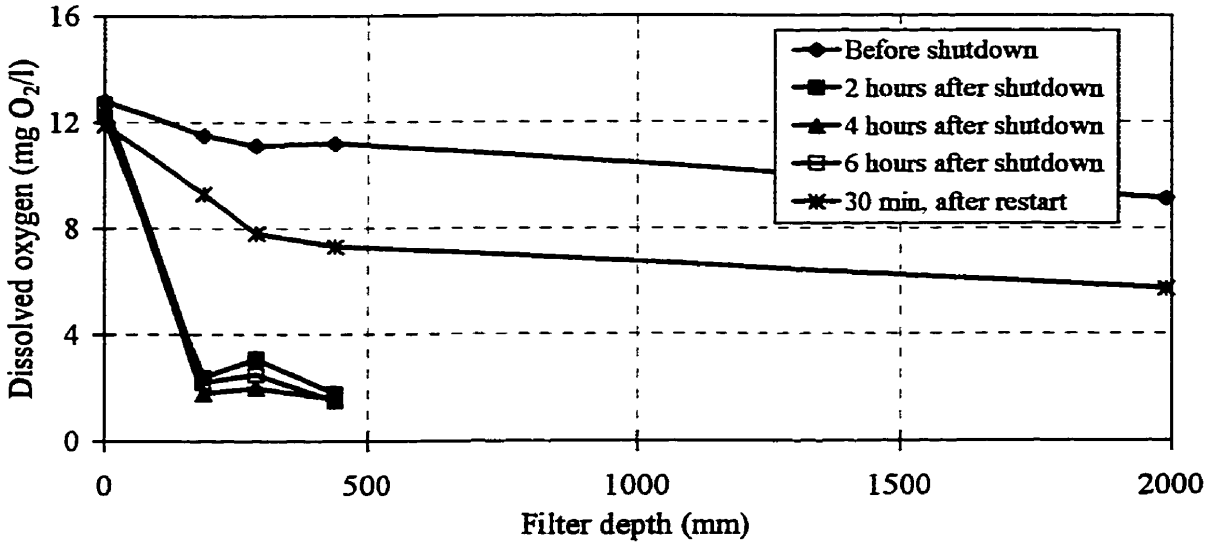
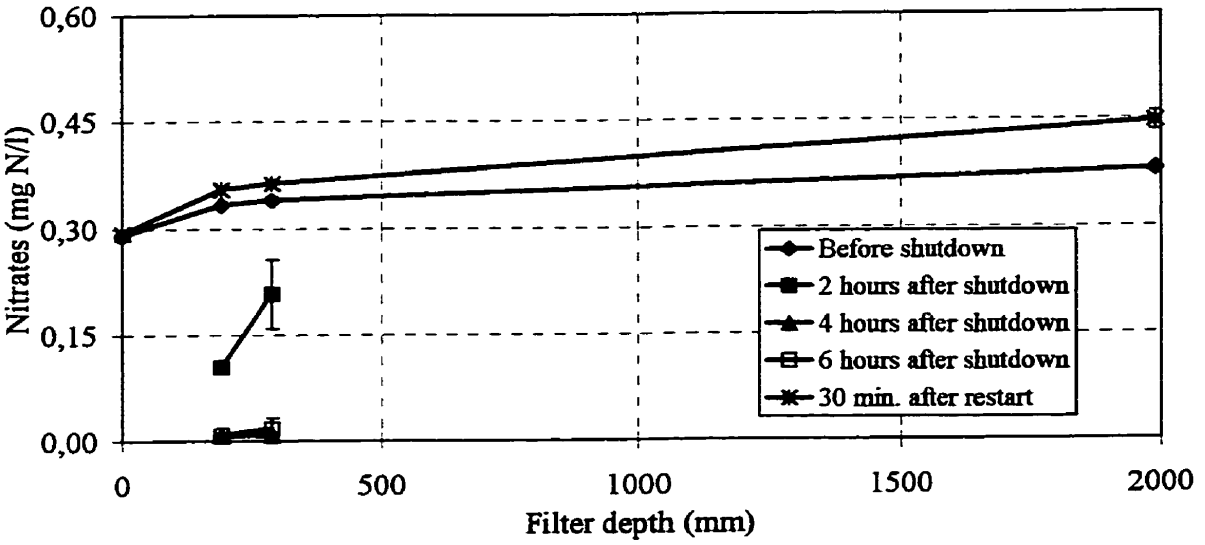


Figure 4.6 Evolution of profiles of dissolved oxygen in the BAC filter on July 8, 1996

a)



b)

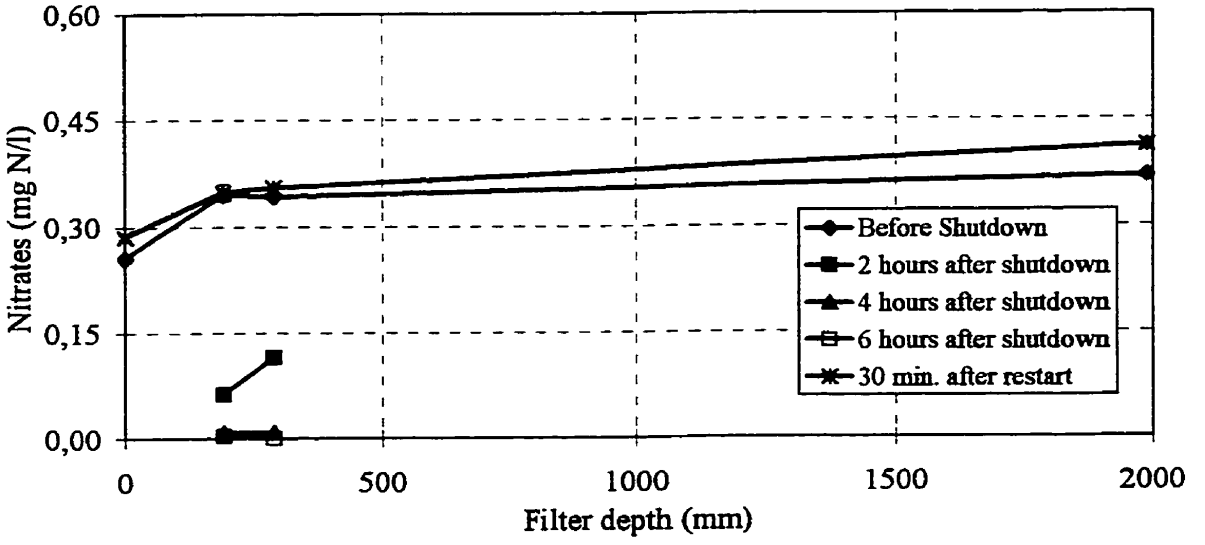
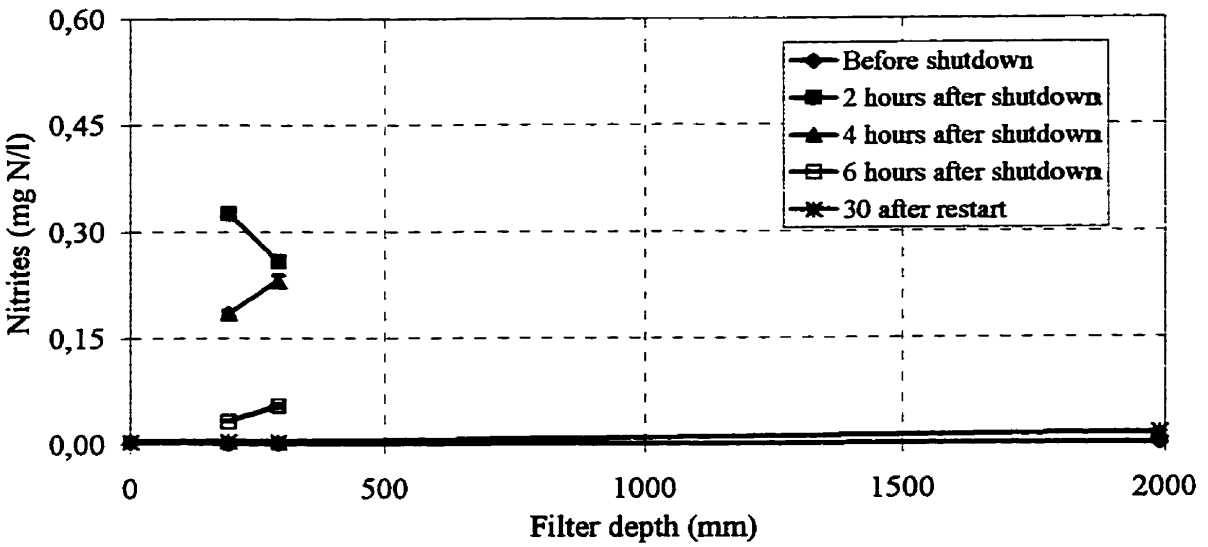


Figure 4.7 Evolution of profiles of nitrates in the BAC filter a) on July 8, 1996 and b) on July 16, 1996 (error bars are standard deviation)

a)



b)

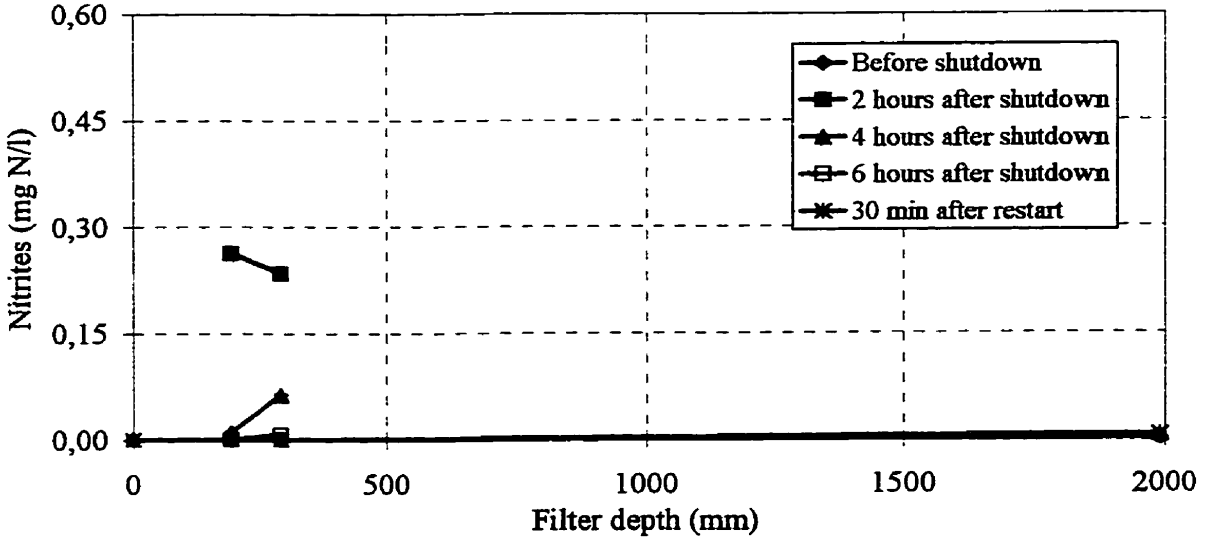
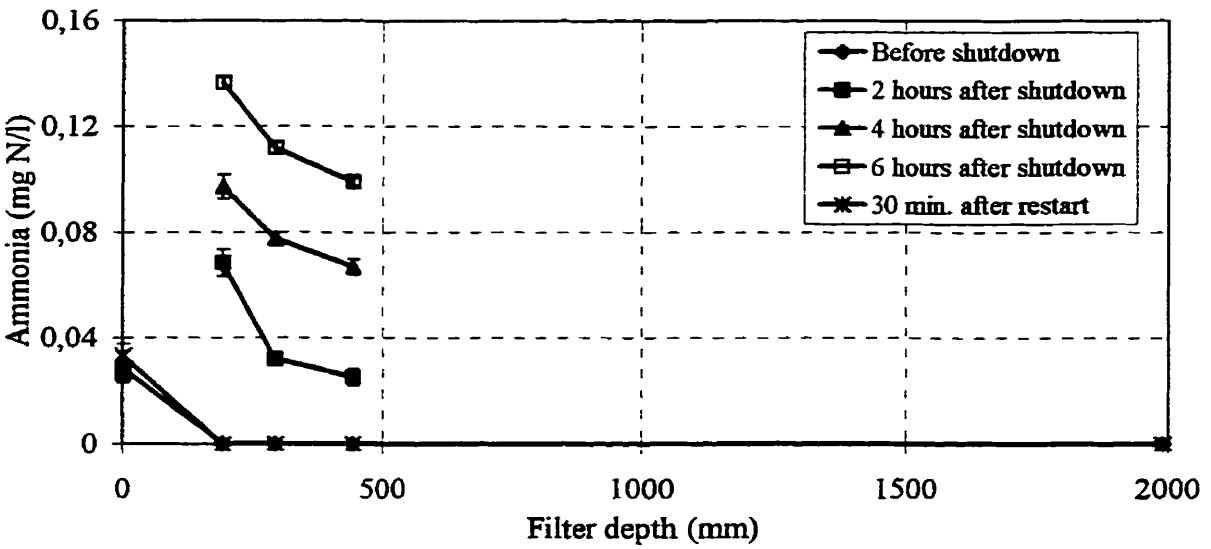


Figure 4.8 Evolution of profiles of nitrites in the BAC filter a) on July 8, 1996 and b) on July 16, 1996 (error bars are standard deviation)

a)



b)

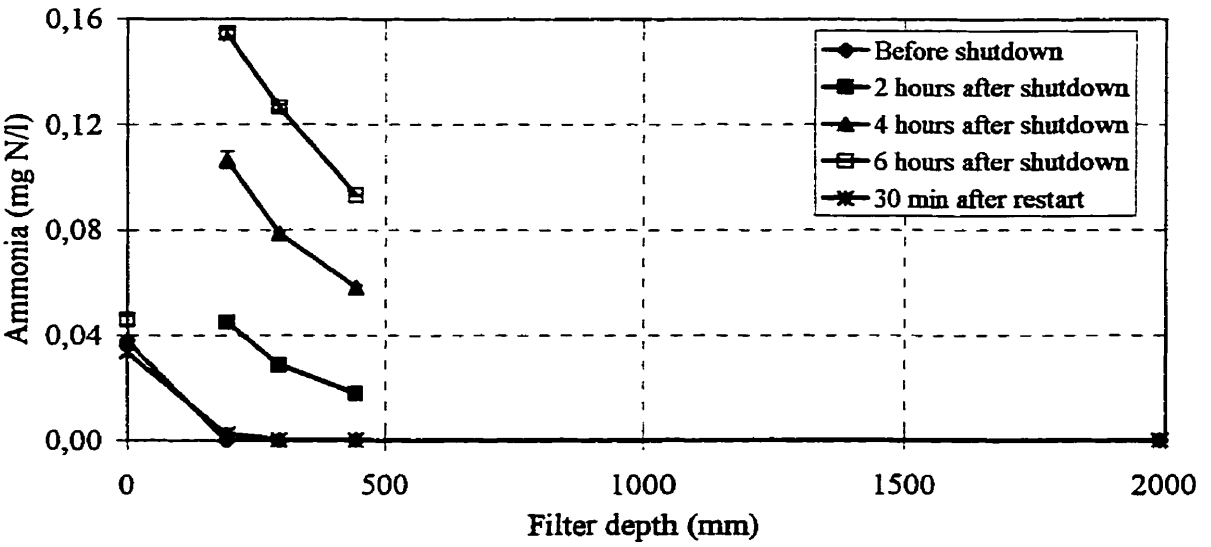


Figure 4.9 Evolution of profiles of ammonia in the BAC filter a) on July 8, 1996 and b) on July 16, 1996 (error bars are standard deviation)

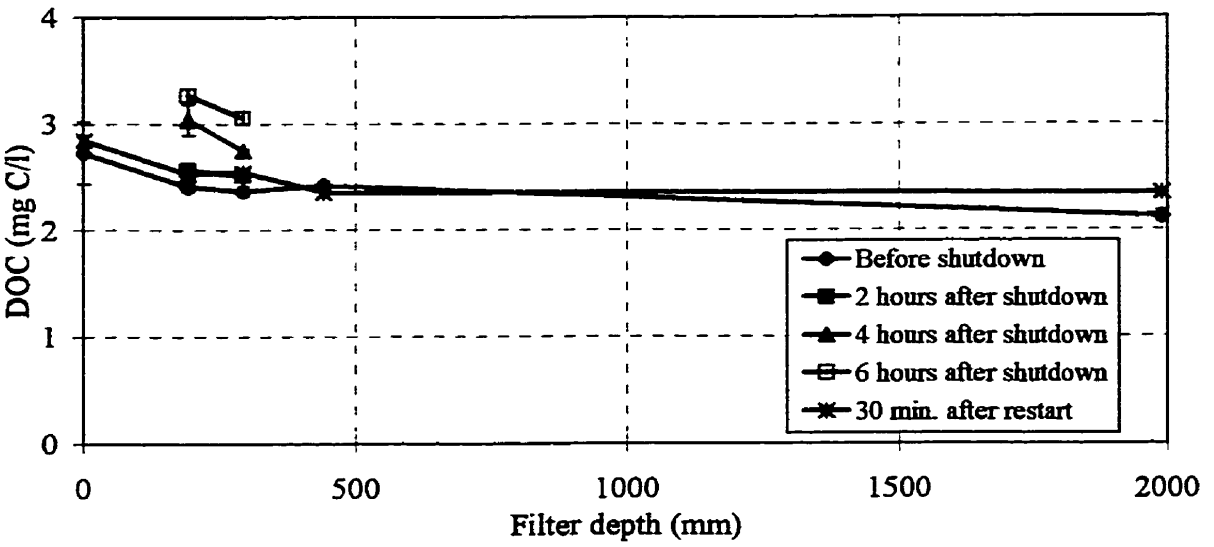


Figure 4.10 Evolution of profiles of DOC in the BAC filter on July 16, 1996 (error bars are standard deviation)

4.3 CONCLUSION

A la lumière des résultats obtenus, un arrêt de filtration de 6 heures est la première étape d'une séquence de lavage efficace pour réduire substantiellement la population d'oligochètes dans les filtres CAB en eau chaude. Le lavage de filtre qui suit l'arrêt de filtratrion est composé d'une séquence de lavage qui permet d'entraîner les oligochètes dans les eaux de lavage. L'arrêt de filtration a permis d'une part de maintenir les densités de population d'oligochètes à un seuil inférieur à 5 naïdides/ml pendant deux cycles de filtration de 96 heures et d'autre part, de limiter la présence de naïdides dans l'effluent des filtres CAB. Ce résultat a été observé 30 minutes après la remise en service du filtre après le premier arrêt de filtration.

La durée de l'arrêt de filtration requise pour réduire la population d'oligochètes dans les filtres peut varier en fonction de la biomasse présente dans les filtres, des concentrations en oxygène dissous et en nitrates de même que la température de l'eau. Ces paramètres influencent l'activité bactérienne qui règne dans les filtres biologiques.

D'autre part, la hausse du nombre de bactéries libres et la présence de sous-prduits d'arrêt de filtration (SPAF) dans l'eau stagnante interstitielle au cours de l'arrêt de filtration met en évidence l'importance de laver un filtre biologique ayant subit un arrêt de filtration. Par contre, une filtration à l'égout pendant une durée minimale établie grâce à des essais pourrait limiter de la même manière les concentrations de SPAF à l'effluent des filtres lors de leur redémarrage

L'arrêt de filtration affecte peu la biomasse fixée. Les densités de biomasse fixée sont demeurées stables avant l'arrêt de filtration et 30 minutes suivant la remise en service du filtre. Les capacités d'enlèvement biologique des filtres CAB sont par conséquent préservées, étant donné que l'abattement du COD et de l'azote ammoniacal demeure le

même après le lavage. Enfin, la présence de SPAF dans l'effluent des filtres CAB n'a pu être observée 30 minutes après la remise en service du filtre.

CHAPITRE 5: CONCLUSIONS GÉNÉRALES

Les travaux de recherche réalisés à l'usine de traitement d'eau potable Sainte-Rose (Ville de Laval, Québec, Canada) ont permis de trouver une solution applicable au problème lié à la présence d'organismes supérieurs dans les usines de traitement d'eau potable. Des méthodes de mesure simples et rapides ont été développées afin d'estimer la population d'oligochètes en usine. Suite à leur développement, les périodes durant lesquelles les oligochètes sont observés en usine ont pu être identifiées. Par la suite, différentes mesures de contrôle ont alors été élaborées et testées à l'échelle usine pour limiter les populations d'oligochètes dans les filtres CAB. De toutes les techniques étudiées, le lavage de filtre incluant un lavage à l'eau à faible débit, un lavage l'air suivi d'un lavage à l'eau à fort débit et précédé d'un arrêt de filtration permet un contrôle efficace de la population d'oligochètes dans les filtres.

5.1 MÉTHODES DE MESURE POUR L'ESTIMATION DES POPULATIONS DES OLIGOCHÈTES DANS LES USINES DE TRAITEMENT D'EAU POTABLE

Les résultats obtenus par la méthode de mesure des densités d'oligochètes d'échantillons de matériau filtrant prélevés dans les filtres CAB montrent que:

- la méthode est précise;
- le coefficient de variation est inférieur à 40 % lorsque les densités d'oligochètes sont supérieures à 5 naïdides/ml;
- la source de variation la plus importante réside dans la profondeur à laquelle l'échantillon est prélevé et reflète les variations de densités de naïdides dans les filtres CAB;
- les densités d'oligochètes sont plus élevées en surface des filtres CAB, soit dans les 300 premiers millimètres;

- les densités d'oligochètes peuvent varier entre 0 et 25 naïdides/ml;
- la méthode pourrait être utilisée pour évaluer la population d'autres organismes supérieurs.

La méthode de mesure des concentrations d'oligochètes indique que:

- la méthode permet de détecter et de déterminer rapidement la concentration d'oligochètes en différents points d'échantillonnage dans une usine de traitement d'eau potable à l'aide d'une simple colonne de filtration retenant les oligochètes matures;
- la méthode requiert la filtration en continu pour recueillir un nombre détectable et représentatifs d'organismes et est par conséquent moins sensible pour des variations de concentration d'oligochètes sur de courtes durées;
- la méthode pourrait être utilisée pour évaluer la présence de d'autres organismes supérieurs en usine.

5.2 SUIVI ANNUEL DES POPULATIONS D'OLIGOCHÈTES DANS LES FILTRES À CHARBON ACTIF BIOLOGIQUE DANS LES USINES DE TRAITEMENT D'EAU POTABLE

L'utilisation des méthodes de mesure développées au début de l'étude a permis de déterminer les périodes durant lesquelles les oligochètes sont présents dans l'usine de traitement d'eau potable Sainte-Rose. Ainsi, :

- de janvier à juin, les oligochètes ne sont pas détectés dans les filtres CAB avec les méthodes de mesure utilisées, la température de l'eau augmente alors de 0,5 à près 20°C;
- de juin à juillet, les densités d'oligochètes dans les filtres CAB augmentent rapidement alors que la température de l'eau approche 20°C, la population d'équilibre est atteinte en juillet; les oligochètes sont détectés alors dans l'effluent des filtres CAB quand les

densités d'oligochètes en surafce sont supérieurs à 5 naidids/ml, mais aussi dans une moindre mesure dans l'effluent des filtres SA ;

- de juillet à septembre, la population d'oligochètes dans les filtres CAB demeure stable alors que la température de l'eau varie entre 20 et 25°C; des oligochètes sont présents dans l'effluent des filtres CAB durant toute cette période;
- de septembre à décembre, la population d'oligochètes dans les filtres CAB diminue à mesure que la température de l'eau baisse de 20 à 0,5°C; les concentrations d'oligochètes à l'effluent des filtres CAB deviennent nulles en eaux froides.

Les périodes durant lesquelles les oligochètes sont observés en usine peuvent varier d'une année à l'autre en fonction des changements climatiques observés durant l'année.

La reproduction sexuée des oligochètes, qui consiste à la production de cocons lors de conditions environnementales défavorables, est responsable de la survie des oligochètes durant la période froide et est probablement responsable de l'apparition des oligochètes en usine au mois de juin. Une fois entrés dans l'usine, les oligochètes s'établissent dans un environnement favorable à leur croissance: les filtres CAB. La reproduction asexuée des oligochètes, qui consiste en la fragmentation ou la segmentation d'un individu en deux individus distincts et viables, prend alors la relève et est responsable en majeure partie de l'augmentation de la population d'oligochètes dans les filtres CAB durant les mois de juin et de juillet. Dans des conditions environnementales favorables, la population d'oligochètes peut doubler à tous les 4 à 6 jours jusqu'à ce que les populations d'oligochètes atteignent la population d'équilibre que peut supporter le milieu récepteur, en l'occurrence les filtres CAB.

Durant le suivi, les densités d'oligochètes les plus élevées, soit 25 naïdides/ml ont été mesurées en surface des filtres CAB dans les 300 premiers millimètres alors que la température de l'eau était supérieure à 20°C. Plus en profondeur, les densités

d'oligochètes deviennent inférieures à 2 naïdides/ml. Enfin, lorsque les densités d'oligochètes en surface des filtres CAB sont supérieures à 5 naïdides/ml, des oligochètes peuvent être détectés à l'effluent des filtres.

5.3 TECHNIQUE DE CONTRÔLE DES OLIGOCHÈTES EN USINE: LAVAGE DE FILTRE MODIFIÉ PRÉCÉDÉ D'UN COURT ARRÊT DE FILTRATION

L'étude de différentes mesures de contrôle de la population d'oligochètes dans les filtres biologiques a mis en évidence qu'un arrêt de filtration suivi d'un lavage de filtre avec une séquence de lavage appropriée permet de réduire de façon importante la population d'oligochètes dans les filtres CAB. La séquence de lavage, qui inclut un lavage à l'eau à faible débit (25 m/h), un brassage à l'air (25 m/h) suivi d'un lavage à l'eau à fort débit (35 m/h) permet d'éliminer les oligochètes ayant migré du milieu filtrant vers la tête d'eau surplombant le filtre. Les densités d'oligochètes dans la couche supérieure de matériau filtrant sont fortement réduites lorsque cette prodédure est appliquée. Suite à l'utilsiation de cette technique, les densités d'oligochètes dans la couche supérieure de matériau filtrant demeurent faibles, soit à un niveau inférieur à 5 naïdides/ml pendant au moins deux cycles de filtration de 96 heures. La population d'oligochètes a toutefois tendance à augmenter durant cette période probablement à cause de la reproduction asexuée des oligochètes. La réalisation d'un deuxième arrêt de filtration, 192 heures après le premier arrêt de filtration n'a pas permis de réduire autant les densités d'oligochètes que lors du premier arrêt de filtration, étant donné que les densités d'oligochètes avant le second arrêt de filtration étaient beaucoup plus faibles que celles observées avant le premier arrêt de filtration.

A la lumière des résultats obtenus, une bonne stratégie de contrôle de la population d'oligochètes dans les filtres CAB consisterait à effectuer un arrêt de filtration à tous les 3 ou 4 cycles de filtration de 96 heures afin de limiter la population d'oligochètes dans les

filtres en eau chaude. Lorsque les densités d'oligochètes en surface des filtres sont inférieures à 5 naïdides/ml, il n'est pas nécessaire d'effectuer un arrêt de filtration suivi d'un lavage de filtre modifié.

La durée de l'arrêt de filtration dépend des conditions existant dans le filtre, particulièrement de la densité de la biomasse dans les filtres biologiques, de la température de l'eau et de la concentration en oxygène dissous et en nitrates. Ainsi, lorsque l'eau est realtivement froide, la biomasse peut être moins active provoquant le ralentissement de l'activité bactérienne et l'augmentation du temps requis pour le développement de conditions anoxies et anaérobies. De la même manière, des niveaux de biomasse plus faibles sont associés à des taux de consommation de l'oxygène dissous et de nitrates dans l'eau plus faibles et par conséquent, le ralentissement du développement de conditions anoxies et anaérobies. Enfin, l'arrêt de filtration suivi d'un lavage de filtre modifié n'est pas requis en absence d'une population d'oligochètes importante en eaux froides.

L'application de la technique de contrôle proposée permet de maintenir les capacités d'enlèvement biologique des filtres. En effet, les analyses montrent que les capacités d'enlèvement du COD et de l'azote ammoniacal avant et après l'application de la technique de lavage sont conservées. Les densités de biomasse fixée sont maintenues après le lavage précédé d'un arrêt de filtration par rapport à celles mesurées avant l'arrêt.

Cependant, l'analyse de la qualité de l'eau qui a stagné dans le filtre CAB lors de l'arrêt de filtration a mis en évidence l'importance de laver le filtre suite à un arrêt de filtration. Le COD, l'azote ammoniacal et les nitrites qui ont augmenté suite à l'arrêt de filtration doivent être évacués à l'égout afin de ne pas introduire de sous-produits d'arrêt de filtration dans les eaux potables.

5.4 RECOMMANDATIONS

A la lumière des travaux de recherche réalisés à l'usine de traitement d'eau potable Sainte-Rose, plusieurs recommandations peuvent être émises quant aux applications des résultats de cette étude. Ces recommandations s'appliquent aussi pour d'autres usines ayant des problèmes similaires avec les oligochètes. Les recommandations émises sont les suivantes:

- faire un suivi de la population d'oligochètes dans les filtres biologiques en utilisant les méthodes de mesure décrites et proposées au chapitre 2 afin de déterminer les périodes durant lesquelles les oligochètes sont présents dans les filtres;
- faire un lavage de filtre modifié, qui inclut 1) un arrêt de filtration de durée à déterminer selon les taux de consommation d'oxygène dissous 2) un rinçage à faible débit d'eau (30-35 m/h), un brassage à l'air (25 m/h) suivi d'un rinçage à plus fort débit d'eau (40-45 m/h), lorsque les densités d'oligochètes en surface des filtres CAB sont supérieures à 5 naïdides/ml.
- augmenter la durée de filtration à l'égout suite à un arrêt de filtration selon la vitesse superficielle de filtration lors de la remise en service du filtre pour éviter le passage d'oligochètes et de sous-produits d'arrêt de filtration dans les eaux potables

5.5 POURSUITE DES TRAVAUX DE RECHERCHE

Plusieurs champs d'étude n'ont pu être abordés au cours de cette recherche et pourraient faire l'objet de recherches plus poussées dont:

- le suivi des organismes supérieurs dans les réseaux de distribution;
- l'impact d'un arrêt de filtration sur les capacités d'enlèvement physiques tels que l'enlèvement des particules et la réduction de la turbidité;
- l'impact à long terme de plusieurs arrêts de filtration sur l'opération des filtres biologiques;

- l'identification des différentes espèces de macro-organismes et de bactéries présentes dans les filtres biologiques pour mieux en comprendre les interactions.

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Annexe A : Conférence présentée à l'AQTE, Montréal, 1996

« Contrôle des annélides dans les filtres à charbon actif biologique »

CONTRÔLE DES ANNÉLIDES DANS LES FILTRES À CHARBON ACTIF BIOLOGIQUE

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INTRODUCTION

Le resserrement prochain des normes de qualité en matière d'eau potable incite de plus en plus de villes et de municipalités à doter leur usine de traitement d'eau potable d'une étape de filtration biologique. En effet, plusieurs études ont montré que la filtration sur charbon actif biologique (CAB) précédé d'une étape d'ozonation peut répondre à ce besoin grandissant d'améliorer les qualités physico-chimiques et biologiques de l'eau potable (PRÉVOST et *al.* 1990).

La majorité des études ayant porté sur l'efficacité des filtres CAB en période de filtration, peu d'études ont été effectuées afin de maintenir la stabilité de l'efficacité biologique des filtres CAB. Les méthodes de lavage employées pour libérer les filtres CAB de leurs impuretés ou encore l'impact de la mise à l'arrêt d'un filtre sont d'autant

d'événements importants à considérer lors de l'exploitation de filtres biologiques, car ils peuvent influencer les qualités physico-chimiques et biologiques de l'eau traitée (NIQUETTE et *al.* 1995; MILTNER et *al.* 1992).

Généralement, les critères de lavage des filtres sont basés sur la turbidité à de leur effluent, sur leurs pertes de charge ou sur la période de filtration maximale. Pour les filtres biologiques, un quatrième critère devrait être considéré : le contrôle des populations de macro-invertébrés présents dans ces filtres. Les lavages de filtres CAB doivent donc être réalisés de façon à prévenir la prolifération de ces organismes dans le milieu filtrant tout en limitant leur présence dans l'eau filtrée et par conséquent, dans le réseau de distribution.

OBJECTIFS

Les objectifs de cette étude étaient: 1) d'évaluer différentes méthodes d'exploitation permettant le contrôle de la population d'annélides présents dans les filtres CAB et dans l'eau filtrée; 2) de mesurer l'effet de différents types de lavage de filtre sur la répartition de la biomasse fixée et des annélides dans les filtres CAB; 3) de proposer une stratégie de lavage de filtre simple et peu coûteuse permettant le contrôle de la population des annélides dans les filtres CAB.

MATÉRIEL ET MÉTHODES

MATÉRIEL

L'étude a été réalisée sur les filtres CAB industriels de l'usine de filtration Sainte-Rose (6 filtres CAB, 110 000 m^3/d, Ville de Laval, Québec, Canada) entre septembre 1995 et septembre 1996. La chaîne de traitement de l'usine Sainte-Rose est présentée à la Figure 1. Un carotteur a été utilisé pour prélever des échantillons du milieu filtrant, tandis que des prises en acier inoxydable munies de tamis disposées à différentes profondeurs dans le filtre ont permis le prélèvement d'échantillons liquides.

Les caractéristiques des filtres échantillonnés sont présentées au Tableau 1. Trois techniques de lavage ont été évaluées : 1) le lavage à l'eau seulement à débit élevé (#1); 2) le lavage à l'air suivi d'un lavage à l'eau à débit variable (#2); 3) l'arrêt de filtration suivi d'un lavage à l'eau à faible débit, d'un lavage à l'air et d'un lavage à l'eau à débit élevé (#3). Pour la troisième technique de lavage (#3), la submergence durant l'arrêt a été fixée à 1 m. Pour tous les filtres, la durée des cycles de filtration était de 96 heures. Les différentes séquences de lavage utilisées sont présentées au Tableau 2. Les techniques de lavage #1 et #2 ont été répétées à quatre reprises de façon consécutive.

MÉTHODES

La méthode de dénombrement des annélides développée évalue le nombre de *Naïs*, un type d'annélides de la famille des oligochètes, contenu dans un échantillon de charbon actif biologique composant un filtre biologique. Comparativement aux méthodes conventionnelles qui consistent à effectuer un décompte visuel des annélides présents dans l'eau évacuée pendant un lavage (ARCOUETTE, 1995), cette nouvelle méthode permet de mesurer les densités d'annélides à différentes profondeurs dans les filtres CAB durant un cycle de filtration ainsi qu'avant et après un lavage. Elle est plus sensible et plus précise que les méthodes précédentes en permettant une évaluation plus fiable des moyens de contrôle utilisés. Cette méthode consiste à prélever un volume fixe de matériau filtrant et à y ajouter de l'eau légèrement chlorée de façon à blanchir les annélides qui deviennent alors inertes et facilement visibles. L'erreur de la méthode est évaluée à 20 % et la limite de détection est de 1 *Naïs* par 4 ml de charbon mouillé.

La mesure de la densité de la biomasse fixée est réalisée par la mesure du potentiel de respiration du glucose radioactif qui détermine la biomasse fixée sur un matériau poreux en mesurant le taux de respiration des micro-organismes (SERVAIS et *al.*, 1991). Une solution de glucose en concentration saturante (1 mM) est ajoutée à un échantillon

de 2 ml de matériau filtrant. Après incubation de 3 heures, le $^{14}CO_2$ produit par les bactéries est recueilli dans une solution absorbante et ensuite détecté à l'aide d'un scintillateur Hewlett Packard, modèle Tri-Carb. L'erreur de la méthode est évaluée à 10 %.

Les concentrations en oxygène dissous ont été mesurées à l'aide d'une sonde électronique à oxygène dissous de HANNA Instruments, modèle HI 8543. Sa précision selon le fabricant est estimée à ± 0,2 mg d'O_2/l.

RÉSULTATS

L'étude des profils d'annélides mesurées dans les filtres CAB entre août 1995 et septembre 1996 a montré que les densités d'annélides les plus élevées se situaient en surface des filtres CAB, généralement dans le premier 0,5 mètre de profondeur. Les densités les plus élevées ont été enregistrées en eaux chaudes (t = 25°C), soit 25 *Naïs*/ml, tandis que les densités les plus faibles ont été observées en eaux froides (t = 1°C), à des valeurs inférieures à la limite de détection de la méthode. Des *Naïs* ont donc été présents dans les filtres jusqu'à la fin décembre 1995 (t = 1°C) et ils n'ont pas été détectés jusqu'au début de juin 1996 (t = 12°C). La colonisation des filtres s'est ensuite effectuée rapidement, les densités d'annélides en surface du filtre passant à plus de 20 *Naïs*/ml en un mois (Figure 2).

D'autre part, la comparaison de l'impact des différentes techniques de lavage sur les densités de biomasse fixée et d'annélides a montré qu'un lavage à l'eau seulement à débit élevé (#1) avait peu d'effets à la fois sur les profils de densités d'annélides et sur les profils de densités de biomasse fixée dans les filtres CAB. Les profils de densités d'annélides mesurées ont généralement été similaires avant et après le lavage, comme le témoigne la Figure 3. Quant aux densités de biomasse fixée, elles ont peu varié et sont demeurées constantes à près de 25 µg C/ml suite à ce lavage (Figure 4).

Le lavage à l'air suivi d'un lavage à l'eau à débit variable (#2) a révélé que les profils de densités d'annélides étaient modifiés par cette technique de lavage (Figure 5). Habituellement, les densités d'annélides étaient plus élevées en profondeur après lavage. Des diminutions importantes de biomasse fixée d'environ 25 % ont été mesurées lors du premier lavage de ce type, passant de 20 µg C/ml à 15 µg C/ml (Figure 6). Par la suite, de faibles hausses de densités de biomasse fixée ont été observées pour tous les lavages subséquents de ce type, sans toutefois permettre d'obtenir des niveaux de densités de biomasse fixée comparables à ceux mesurés dans les autres filtres étudiés (22 µg C/ml comparativement à 26 µg C/ml).

La Figure 7 montre l'impact d'un arrêt de filtration précédant un lavage (#3) sur les densités d'annélides en différentes profondeurs et à différents temps après l'arrêt du filtre CAB (t = 0, 2, 4 et 6 h) et 30 minutes après sa remise en filtration (t = 30 min). 96 heures après le lavage, les densités d'annélides avaient doublé en surface du filtre CAB mais atteignaient des valeurs inférieures à celles obtenues dans les autres filtres étudiés durant la même période. Par ailleurs, durant l'arrêt de filtration, les densités de biomasse fixée se sont soldées par une diminution de moins de 5 % en surface et à près de 20 % en profondeur pour des valeurs initiales de près de 15,5 µg/ml (Figure 8). De plus, les concentrations en oxygène dissous à l'intérieur du filtre ont diminué constamment pour atteindre environ 2 mg O_2/l 2 heures après l'arrêt et ont augmenté à nouveau aux niveaux initiaux 30 minutes après le lavage (Figure 9).

DISCUSSION

L'évolution des profils de densités d'annélides dans les filtres CAB étudiés durant un an montre que les densités d'annélides mesurées sont plus élevées en été, soit entre juin à octobre (t = 15°C). En effet, c'est durant cette période que la colonisation des filtres par les annélides s'effectue. Une fois établis, les *Naïs* demeurent dans les filtres jusqu'à ce que la température de l'eau diminue (t = 1°C).

La comparaison des méthodes de lavage a montré que le lavage à l'eau seulement à débit élevé (#1) ne favorise pas l'augmentation de la population d'annélides dans les filtres CAB. En effet, durant la période d'analyse, les densités d'annélides ont même légèrement diminué. Par ailleurs, l'impact de ce type de lavage sur la biomasse fixée est faible, étant donné que les valeurs de densités de biomasse fixée après lavage sont similaires ou légèrement plus élevées à celles mesurées avant lavage. Cependant, l'usage répétitif de cette technique de lavage peut favoriser la formation d'agglomérats biologiques étant donné l'absence de lavage à l'air.

Un lavage à l'air suivi d'un lavage à l'eau à débit élevé (#2) ne permet pas de réduire la population d'annélides présente dans le filtre même après 4 lavages consécutifs de ce type. Cependant, les profils d'annélides sont perturbés après lavage. L'utilisation d'air en début de lavage combiné au lavage à l'eau à débit variable peut favoriser la répartition des annélides plus en profondeur dans le filtre ou encore favoriser l'augmentation de la population d'annélides. Cette augmentation peut être causée par un sectionnement des annélides formant ainsi de nouveaux individus distincts (Figure 5) (LAUGIER, 1988). Également, ce type de lavage favorise le décrochage de la biomasse fixée des grains de charbon, étant peu acclimatée à des variations importantes de débits, et se traduit par une baisse de densités de biomasse fixée après lavage (Figure 6).

L'arrêt de filtration suivi d'un lavage à l'eau à faible débit, d'un lavage à l'air et d'un lavage à l'eau à débit élevé (#3) semble être la technique de lavage la plus adéquate pour contrôler les annélides dans les filtres biologiques. En effet, le lavage précédé d'un arrêt de filtration réduit de façon importante la population d'annélides dans le filtre CAB (Figure 7). Ainsi, le lavage a permis de réduire d'environ 50% la population totale d'annélides 4 heures après l'arrêt de filtration et d'environ 90% 30 minutes après la remise en filtration. Ces baisses de densités d'annélides dans le filtre se traduisent par le

déplacement massif des *Naïs* du lit filtrant vers la tête d'eau surplombant le filtre (visuellement observable). Or durant l'arrêt, les bactéries fixées sur le matériau filtrant consomment l'oxygène dissous présent dans l'eau interstitielle jusqu'à ce que des conditions anoxies et anaérobies se développent (Figure 9). D'une part, l'absence d'oxygène dissous expliquerait la remontée des *Naïs* vers la surface, étant donné que les *Naïs* ont une respiration cutanée (BRINKHURST et GELDER, 1991). D'autre part, les diminutions de densités de biomasse fixée mesurées sont sans doute le résultat d'un manque d'oxygène dissous facilement accessible par les bactéries aérobies et aérobies facultatives. En absence prolongée d'oxygène, ces dernières peuvent se décrocher ou subir une lyse. Par ailleurs, l'utilisation d'un lavage à l'eau à faible débit s'avère nécessaire afin d'évacuer les *Naïs* présents dans la tête d'eau vers la goulotte de lavage et, par conséquent, d'éliminer la possibilité aux *Naïs* de s'attacher à nouveau aux grains de CAB.

CONCLUSION

La plupart des filtres utilisés dans les usines de traitement d'eau potable sont colonisés par des bactéries. Ceci implique que des prédateurs de bactéries, comme les annélides, peuvent se développer et proliférer dans ces filtres. Il est donc important de limiter la présence de macro-invertébrés comme les annélides dans les filtres pour éviter leur passage à l'eau filtrée.

L'utilisation de la méthode de dénombrement des annélides peut servir à d'autres fins, par exemple pour le dénombrement de certains types de macro-organismes comme les nématodes ou les *Chironomus*. Dans cette perspective, l'usage périodique de la méthode pourrait permettre d'identifier les types de macro-invertébrés qui peuplent les filtres CAB et de suivre ainsi l'évolution du niveau de colonisation.

Enfin, le lavage précédé d'un arrêt de filtration constitue un outil de contrôle simple et efficace de la colonisation des filtres par les annélides. Un arrêt de filtration entre 4 et 6 heures peut réduire la population d'annélides dans les filtres biologiques. De légères modifications à la séquence de lavage du filtre seraient cependant nécessaires. Comme les *Naïs* ne sont pas présents dans les filtres durant toute l'année, cette méthode de lavage peut être utilisée de manière sporadique, principalement en été, afin de contrôler la population d'annélides dans les filtres.

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TABLEAU 1 Caractéristiques des matériaux filtrants des filtres CAB industriels de l'usine Sainte-Rose

Caractéristiques	Filtres		
No du filtre	2	5	6
Type de Charbon	Calgon F400	Calgon F400	Calgon F400
Année de la mise en service	Octobre 1984	Juillet 1987	Juillet 1987
Épaisseur de matériau filtrant (m)	1,63	2,07	1,82
Technique de lavage	#1	#3	#2

TABLEAU 2 Séquences de lavage des filtres CAB industriels de l'usine Sainte-Rose

ÉTAPES DE LA SÉQUENCE DE LAVAGE	Vitesse (m/h)	Durée (min)
1- Lavage à l'eau seulement à débit élevé (#1)		
Lavage à l'eau à débit élevé	40-45	20
2- Lavage à l'air suivi d'un lavage à l'eau à débit variable (#2)		
Lavage à l'air	20-25	2
Lavage à l'eau à débit élevé	40-45	16
Lavage à l'eau à débit variable (10 pulsations)	0-65	10
3- Arrêt de filtration suivi d'un lavage à l'eau à faible débit, d'un lavage à l'air et d'un lavage à l'eau à débit élevé (#3)		
Arrêt de filtration	---	360 (6 h)
Lavage à l'eau à faible débit	30-35	5
Lavage à l'air	20-25	2
Lavage à l'eau à débit élevé	40-45	16

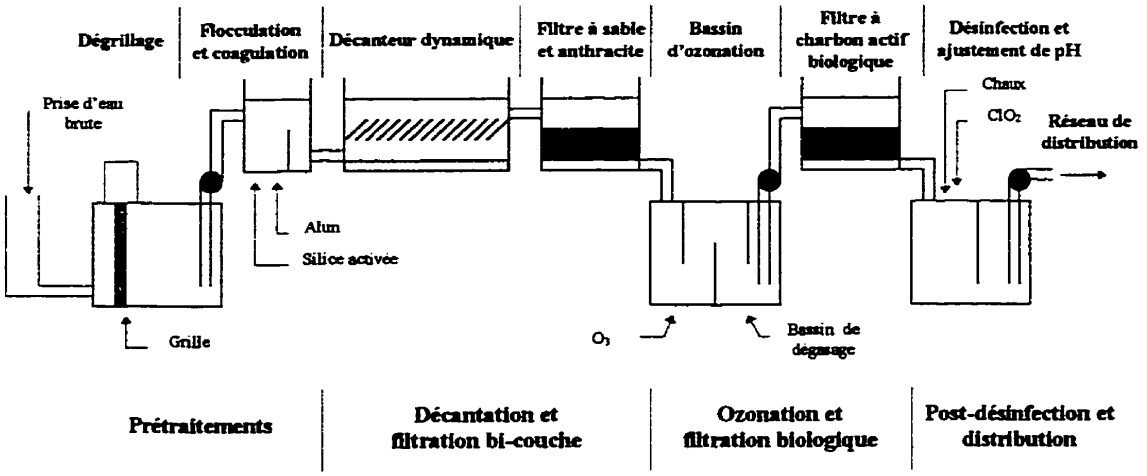

Figure 1 Chaîne de Traitement de l'usine Sainte-Rose

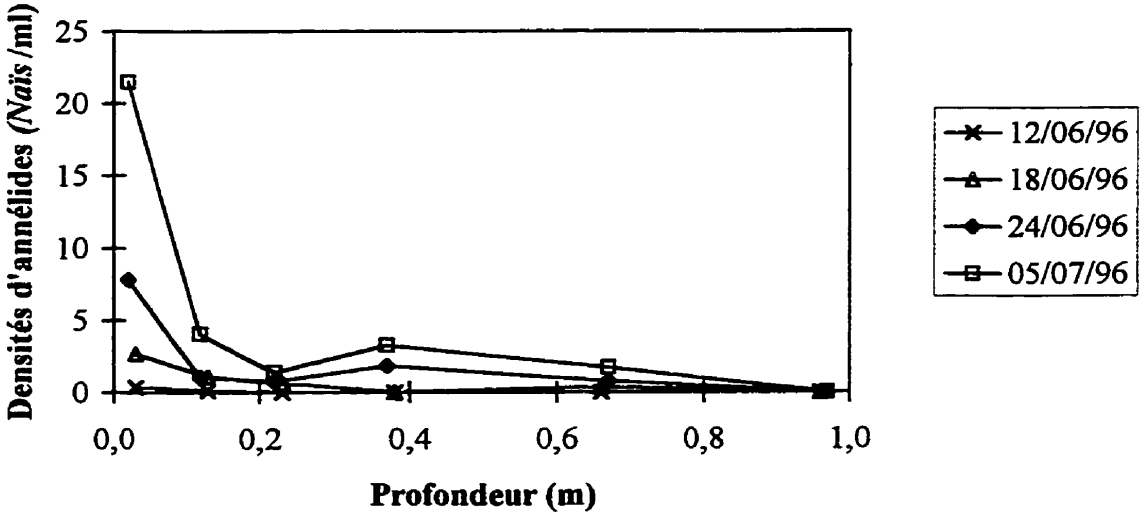

Figure 2 Évolution des profils de densités d'annélides dans un filtre CAB entre juin et juillet 1996

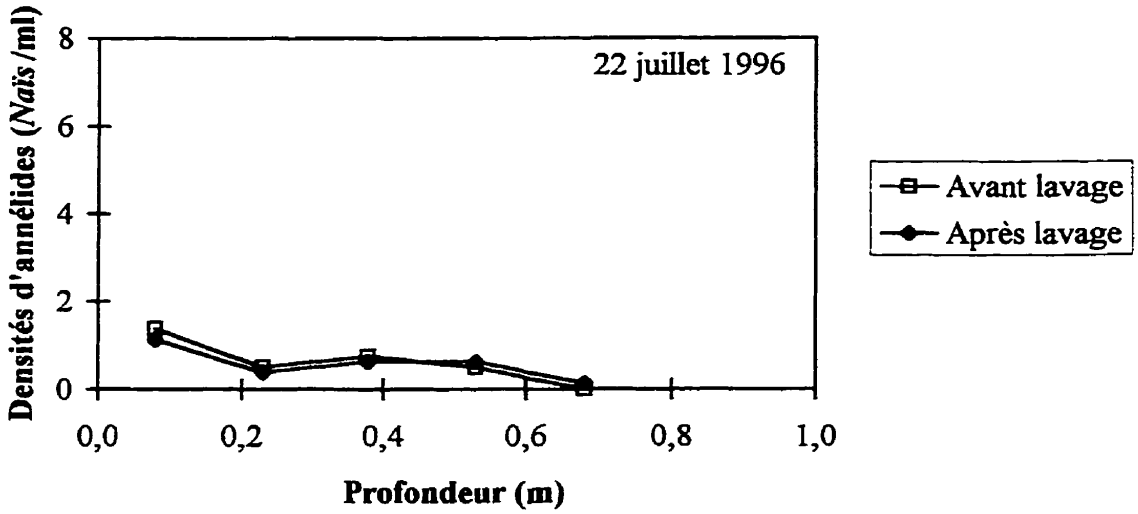

Figure 3 Impact d'un lavage à l'eau seulement à débit élevé (#1) sur les densités d'annélides

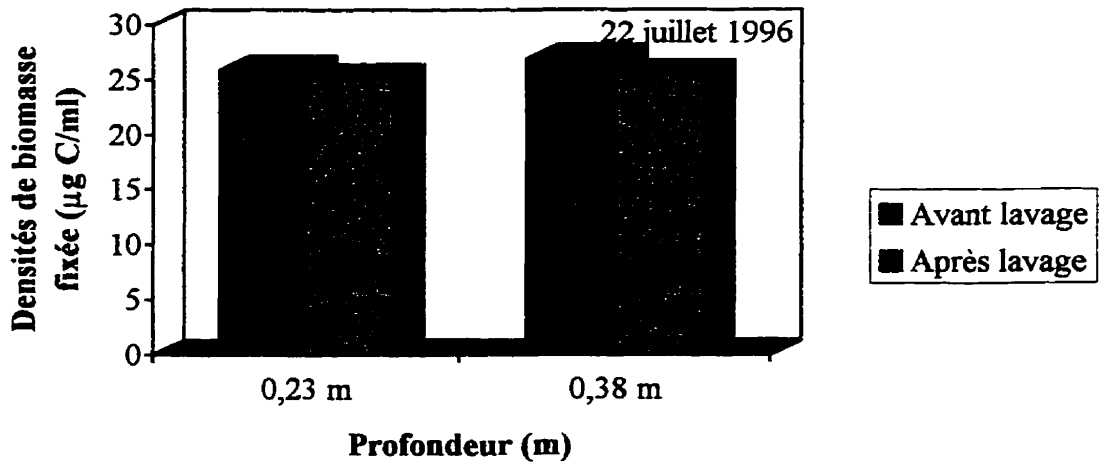

Figure 4 Impact d'un lavage à l'eau seulement à débit élevé (#1) sur les densités de biomasse fixée

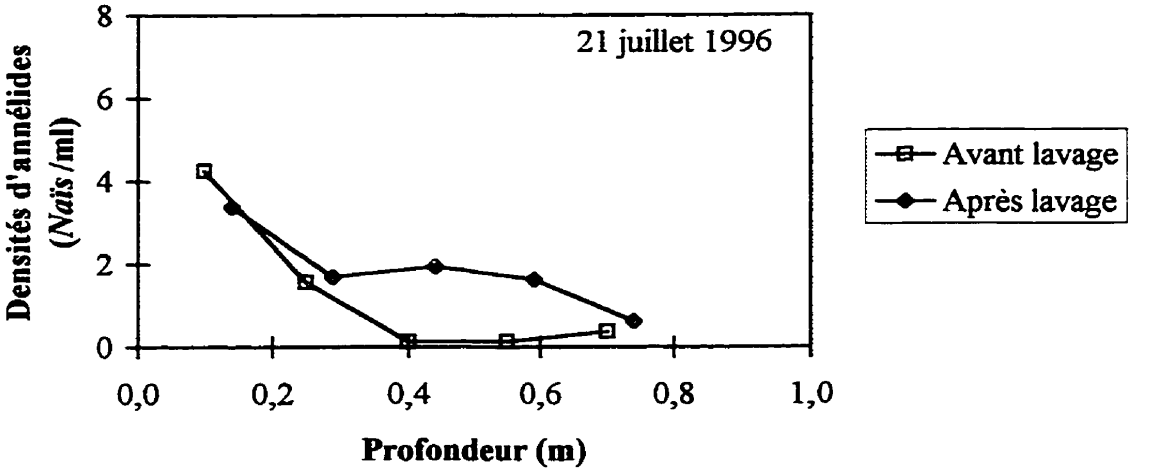

Figure 5 Impact d'un lavage à l'air suivi d'un lavage à l'eau à débit variable (#2) sur les densités d'annélides

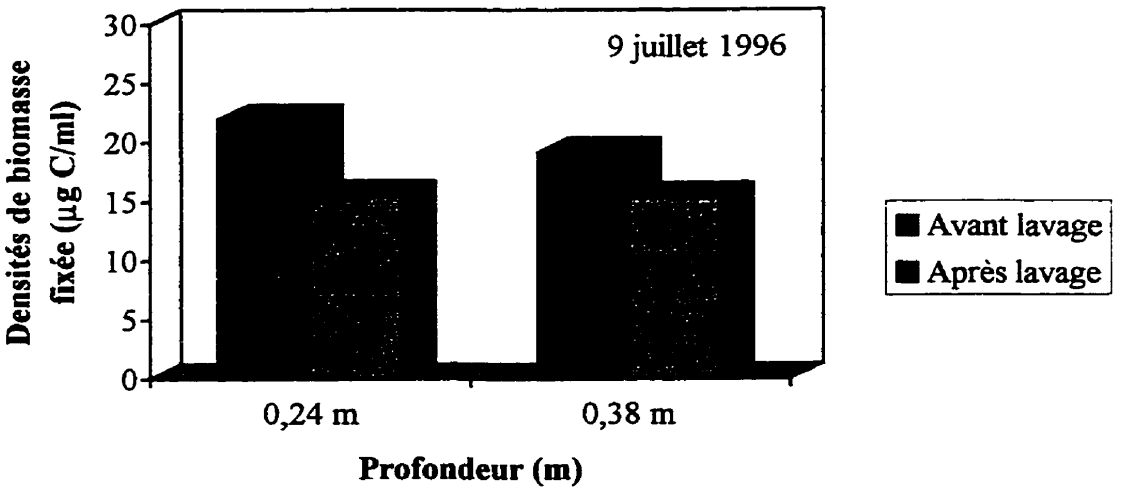

Figure 6 Impact d'un lavage à l'air suivi d'un lavage à l'eau à débit variable (#2) sur les densités de biomasse fixée

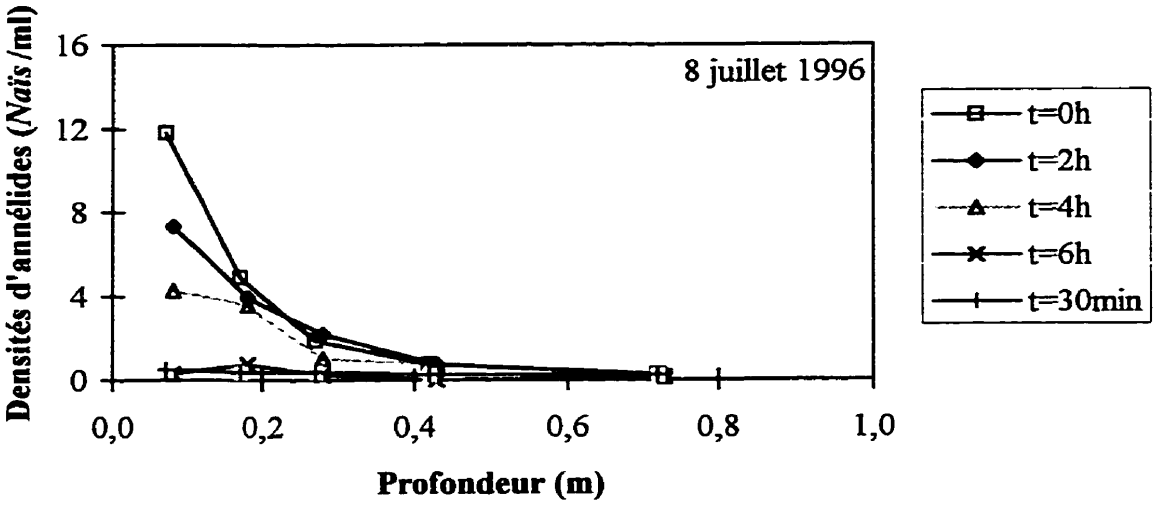

Figure 7 Impact d'un arrêt de filtration suivi d'un lavage à l'eau à faible débit, à l'air et à l'eau à débit élevé (#3) sur les densités d'annélides

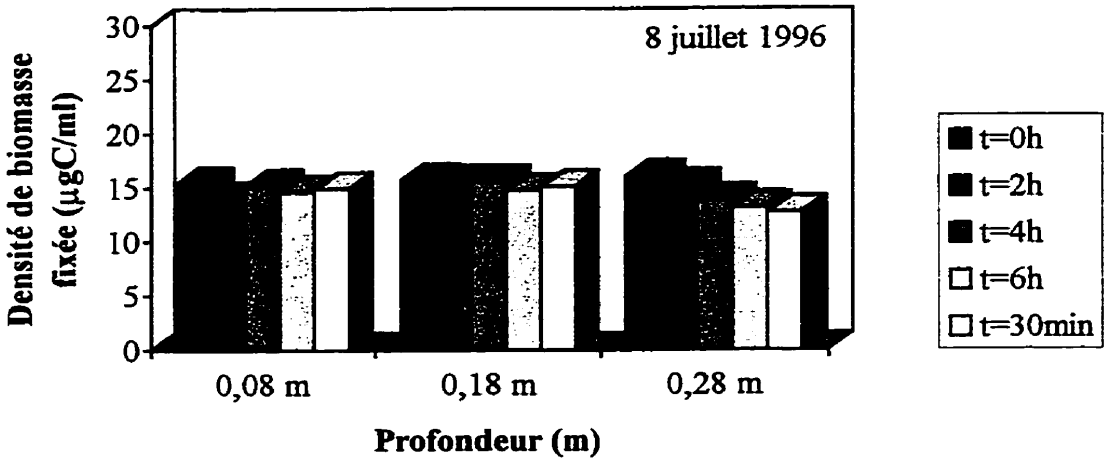

Figure 8 Impact d'un arrêt de filtration suivi d'un lavage à l'eau à faible débit, à l'air et à l'eau à débit élevé (#3) sur les densités de biomasse fixée

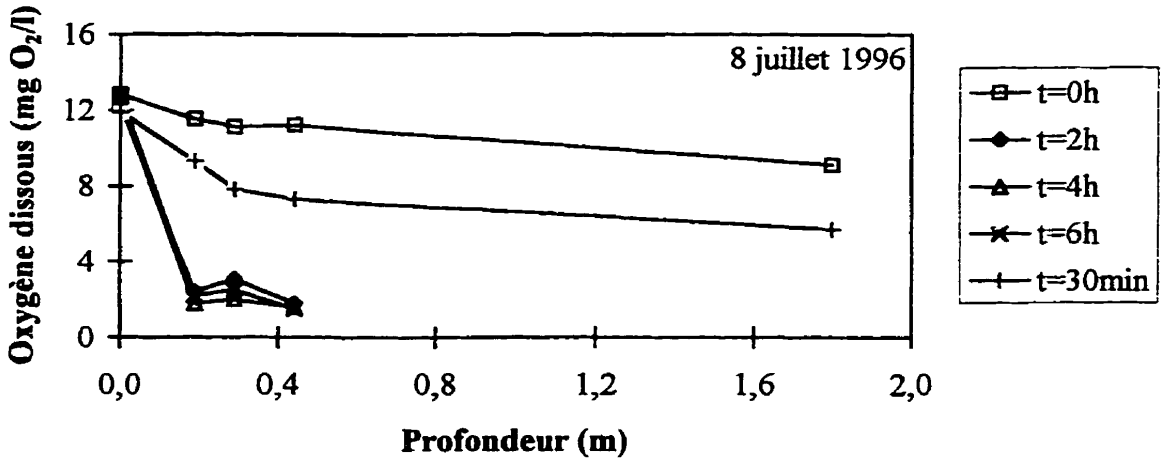

Figure 9 Impact d'un arrêt de filtration suivi d'un lavage à l'eau à faible débit à l'air et à l'eau à débit élevé (#3) sur les concentrations d'oxygène dissous

Annexe B : Conférence présentée au WQTC-AWWA, Boston, 1996

« Controlling Annelids in Biological Activated Carbon Filters »

CONTROLLING ANNELIDS IN BIOLOGICAL ACTIVATED CARBON FILTERS

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ABSTRACT

The objective of this study was to evaluate the impact of backwashing techniques for controlling annelids in BAC filters. The results have shown that the density profiles of the annelids present in the BAC filters studied over a one-year period, were higher in the summer (20 *Naïs*/ml, t = 15 - 25 °C) and lower in the winter (detection limit, t = 1°C). Filter backwashing with water only at a medium flow rate had little effect on the density profiles of annelids and fixed biomass in BAC filters. Air scour followed by backwashing with water at a variable flow rate revealed that this backwashing technique modified the density profiles of annelids and showed lower fixed biomass densities. A filter shutdown

followed by backwashing with water at a low flow rate, then air scour followed by backwashing with water at a medium flow rate was found to reduce the population of annelids in BAC filters about 50 % of the total annelid population four hours after the shutdown, and about 90 % thirty minutes after the start-up of filtration. Backwashing preceded by a filter shutdown is proved to be a simple and effective method for controlling the colonization of filters by annelids. A filter shutdown between four and six hours can reduce an annelid population in a biological filter. This technique of backwashing can be used sporadically when required, primarily in the summer, to control annelid populations in BAC filters.

INTRODUCTION

The imminent tightening of water quality standards with respect to drinking water is prompting an increasing number of cities and towns to add a biological filtration step to their drinking water treatment processes. A number of studies have, in fact, shown that filtration on biological activated carbon (BAC) preceded by ozonation can respond to the growing need to improve the physico-chemical and biological qualities of drinking water (PRÉVOST *et al.*, 1990).

While the majority of studies have looked at the effectiveness of BAC filters during filtration, few have been carried out with a view to maintaining the stability of the performance of BAC filters. It is equally important, for example, to consider the backwashing techniques used to clean BAC filters and the impact of the filter shutdown in connection with the operation of biological filters, because these events can influence the physico-chemical and biological properties of the filtered water (NIQUETTE *et al.*, 1995; MILTNER *et al.*, 1992).

In general, the criteria for backwashing a filter are based on the turbidity of the filter's effluent, on the filter's headlosses or on the maximal duration of filtration. For biological filters, a fourth criterion should be considered: control of the macro-invertebrates present in these filters. The backwashing of BAC filters must, therefore, be carried out in such a way as to prevent the proliferation of these organisms in the filter medium, while at the same time limiting their presence in the filtered water and, consequently, in the distribution network.

OBJECTIVES

The objectives of this study were: 1) to evaluate various methods of filter operation which would permit the control of the annelid populations present in BAC filters and in the filtered water; 2) to measure the effect of different types of filter backwashing on the distribution of the fixed biomass and of the annelids present in BAC filters; and 3) to propose a simple and inexpensive strategy for backwashing filters which would permit the control of annelid populations in BAC filters.

MATERIALS AND METHODS

MATERIALS

The study was carried out on industrial BAC filters at the St. Rose filtration plant in the City of Laval, Québec, Canada (6 BAC filters, nominal capacity of 110 000 m^3/d) between August 1995 and September 1996. A schematic flow diagram of the St. Rose plant is represented in Figure 1. A core drill was used to extract samples from the filter media, and stainless-steel taps fitted with screens were placed at various depths in the filter and used to remove liquid samples.

The characteristics of the filters sampled are presented in Table 1. Three backwashing techniques were evaluated: 1) backwashing with water only at a medium flow rate (#1); 2) air scour followed by backwashing with water at a variable flow rate

(#2); and 3) filter shutdown followed by backwashing with water at a low flow rate, then air scour and finally backwashing with water at a medium flow rate (#3). For the third backwashing technique (#3), submergence during filter shutdown was fixed at 1 m. The duration of the filtration cycle was 96 hours for all the filters. The various backwash sequences used are presented in Table 2. Backwashing techniques #1 and #2 were repeated four times in succession.

METHODS

A method for counting annelids was developed which estimates the number of *Naïs*, a type of annelids belonging to the oligochaetes family, contained in a sample of the biological activated carbon used in a biological filter. In comparison with conventional methods, which involve visual estimation of the number of annelids present in the water discharged during backwashing (ARCOUETTE, 1995), the new method makes it possible to measure annelid densities at different depths in BAC filters during a filtration cycle, as well as before and after filter backwashing. It is more sensitive and more accurate than the earlier methods in that it provides a more reliable assessment of the control methods used. This method consists of taking a filter media sample with a fixed volume and adding water to it which has been chlorinated, with the result that the annelids become inert and white, and therefore visible. The coefficient of variation (CV) of the method has been calculated at 20% and the detection limit at 1 *Naïs* per 4 ml of wet carbon.

The density of the biomass fixed on a porous material is determined by measuring the potential respiration of radiolabeled glucose, which is dependent on the rate of glucose respiration of the micro-organisms by the fixed biomass, and therefore on their density (SERVAIS, *et al.*, 1991). A saturated solution of glucose (1 mM) is added to a sample of 2 ml of filter media. After a 3-hour incubation period, the $^{14}CO_2$ produced by the bacteria is collected in an absorbent solution and then detected by means of a

Canberra Packard scintillator, the Tri-Carb model. The precision of this method has been evaluated at 10 %.

The dissolved oxygen concentrations were measured by means of an electronic probe for dissolved oxygen by HANNA Instruments, model HI 8543. The precision of this instrument, according to the manufacturer, is estimated to be $\pm$ 0.2 mg O_2/l.

RESULTS

The study of annelid profiles measured in BAC filters between August 1995, and September 1996, showed that the highest annelid densities were located on the surface of BAC filters, generally down to a depth of 0.5 meter. The highest densities were recorded in warm water (t = 25°C), about 25 *Naïs*/ml, while the lowest densities were observed in cold water (t = 1°C), at values under the detection limit of the method. *Naïs* were present, therefore, in the filters until December, 1995 (t = 1°C), and were not detected again until June, 1996 (t = 12°C). The colonization of the filters then proceeded rapidly, the annelid densities on the surface of the filter exceeding more than 20 *Naïs*/ml in one month (Figure 2).

At the same time, a comparison of the impact of the various backwashing techniques on the densities of fixed biomass and of annelids have shown that backwashing with water only at a medium flow rate (#1) has little effect on the density profiles of either annelids or fixed biomass in BAC filters. The annelid density profiles measured were generally similar before and after backwashing, as shown in Figure 3. There was little variation in the densities of fixed biomass, which remained constant at about 25 µg C/ml following this backwashing method (Figure 4).

Air scour followed by backwashing with water at a variable flow rate (#2) revealed that this backwashing technique modifies the density profiles of annelids (Figure 5). Usually, the annelid densities were higher at greater depth after backwashing. Considerable reductions in fixed biomass densities (about 25 %) were measured during the first backwashing using this method, from 20 μg C/ml to 15 μg C/ml (Figure 6). After each subsequent backwashing of this type, small increases in the fixed biomass densities were observed, however the higher levels of fixed biomass density measured in the other filters studied were never achieved in this case (22 μg C/ml, compared with 26 μg C/ml for the others).

Figure 7 shows the impact of the shutdown of a BAC filter preceding a backwashing (#3) on the annelid densities at different depths and at different times before shutdown, after shutdown (t = 2, 4 and 6 h), and 30 minutes after start-up of filtration (t = 30 min). Ninety-six hours after backwashing, the annelid densities were increased by a factor 2 at the surface area of the BAC filter, but reached lower values than those obtained in the other filters studied during the same period. Moreover, during shutdown, the final fixed biomass densities measured revealed a reduction of less than 5% in the surface area and nearly 20% deeper for initial values near 15.5 μg C/ml (Figure 8). In addition, the concentrations of dissolved oxygen inside the filter decreases continuously, reaching about 2 mg O_2/l two hours after shutdown, and then went back to the initial levels 30 minutes after backwashing (Figure 9).

DISCUSSION

The evolution of the density profiles of the annelids present in the BAC filters studied over a one-year period showed that these densities were higher in the summer, that is, between June and October (from t = 15°C to t = 25 °C). It is, in fact, at the beginning of this period that the colonization of filters by annelids occurs. Once established, the *Naïs* remain in the BAC filters until the temperature of the water down to

1°C. Therefore, the level of annelid populations depends of the temperature of the raw water.

Comparison of the backwashing methods showed that backwashing with water only at a medium rate of flow (#1) does not promote an increase in the annelid population in BAC filters. The annelid densities even decreased slightly during the comparison period of backwashing techniques. Moreover, the impact of this type of backwashing on the fixed biomass is small, given that the values of the densities of the fixed biomass after backwashing are similar, or slightly higher, than those measured before backwashing. However, the repeated use of this backwashing technique may cause the formation of biological agglomerates as a result of the absence of air scour.

Air scour, followed by backwashing with water at a medium flow rate (#2) does not result in a reduction in the annelid population present in the filter, even after four consecutive backwashings of this type. However, there is perturbation in the annelid profiles after backwashing. The use of air scour at the beginning of the backwashing process combined with backwashing with water at a variable flow rate may promote an increase in the annelid population. This increase may be caused by a sectioning of the annelids, which results in the formation of distinct new individuals (Figure 5) (LAUGER, 1988). As well, this type of backwashing favors the detachment of the fixed biomass from carbon granules. Fixed biomass may be not sufficiently acclimatized to significant variations of high shear stress to prevent a lowering of the density of the fixed biomass (Figure 6).

A filter shutdown followed by backwashing with water at a low flow rate, and then air scour and backwashing with water at a medium flow rate (#3) seems to be the most appropriate backwashing technique for controlling annelids in biological filters. Backwashing preceded by a shutdown was found to significantly reduce the population of

annelids in the BAC filter (Figure 7). In fact, backwashing resulted in a reduction of about 50% of the total annelid population four hours after the shutdown, and of about 90% thirty minutes after backwashing. This lowering of the annelid densities in the filter translates into a massive displacement of *Naïs* from the filter bed towards the water overhanging the filter (observable visually). During shutdown, therefore, the bacteria fixed on the filter material consume the dissolved oxygen present in the interstitial water until anoxic and anaerobic conditions develop (Figure 9). On the one hand, the absence of dissolved oxygen would explain the rise of the *Naïs* to the surface, given that *Naïs* breathe cutaneously (BRINKHURST and GELDER, 1991). On the other hand, reductions in measured fixed biomass densities are the result of a lack of dissolved oxygen which usually is easily accessible to the obligate aerobes and facultative anaerobes. Prolonged lack of oxygen can result in these latter bacteria becoming detached or being subjected to lysis. Moreover, the use of backwashing with water at a low flow rate has been shown to be necessary in order to move the *Naïs* present in the water surface towards the wash-water outlet. Consequently, the possibility of the *Naïs* becoming re-attached to the carbon granules is eliminated.

CONCLUSION

Most filters used in drinking water treatment plants are colonized by bacteria. This implies that the predators of the bacteria, like annelids, can develop and proliferate in these filters. It is important, therefore, to limit the presence of macro-invertebrates like annelids in filters in order to prevent them from passing into the filtered water.

The annelid counting method developed during this study could also be used for other purposes; for example, counting certain types of macro-organisms like nematodes and chironomids. A periodic use of the method can identify different types of macro-invertebrates that might populate BAC filters, in turn making it possible to monitor the level of colonization in the filters.

To summarize, backwashing preceded by a filter shutdown is proved to be a simple and effective method for controlling the colonization of filters by annelids. A filter shutdown of between four and six hours can reduce an annelid population in a biological filter. Since *Naïs* are not present in the filters all year-round, depending of the temperature of the raw water, this technique of backwashing can be used sporadically when required, primarily in the summer, to control annelid populations in filters.

ACKNOWLEDGMENTS

We would like to thank the partners of the Industrial Chair on Drinking Water of the École Polytechnique de Montréal: the Natural Sciences and Engineering Research Council of Canada, the City of Montreal, the City of Laval, John Meunier Inc., the Compagnie Générale des Eaux and Vallée-Lefebvre et Associés. We would also like to thank the staff of the laboratory at the École Polytechnique de Montréal and the operators at the St. Rose drinking water treatment plant for making themselves available to us and for collaborating with us in this research project.

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TABLE 1 Characteristics of industrial BAC filters at St. Rose filtration plant

Characteristics	Filters		
Filter number	2	5	6
Type of carbon	Calgon F400	Calgon F400	Calgon F400
Year of start-up	October 1984	July 1987	July 1987
Depth of filter media (m)	1.63	2.07	1.82
Technique of backwashing	#1	#3	#2

TABLE 2 Backwash sequences for industrial BAC filters at St. Rose filtration plant

STEPS OF BACKWASH SEQUENCE	Backwash Flow Rate (m/h)	BackWash Time (min)
1- backwashing with water only at a medium flow rate (#1)		
- Backwash with water at a medium flow rate	40-45	20
2- Air scour followed by backwashing with water at a variable flow rate (#2)		
- Air scour	20-25	2
- Backwash with water at a medium flow rate	40-45	16
- Backwash with water at a variable flow rate	0-65	10
3- Filter shutdown followed by backwashing with water at a low flow rate, air scour followed by backwashing with water at a medium flow rate (#3)		
- Filter shutdown	—	360 (6 hours)
- Backwash with water at a low flow rate	30-35	5
- Air scour	20-25	2
- Backwash with water at a medium flow rate	40-45	16

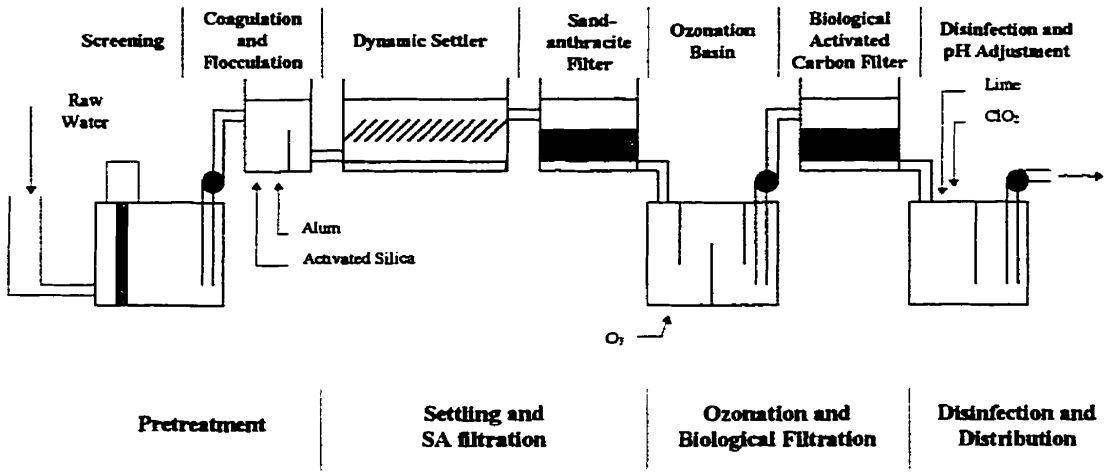

Figure 1 Schematic flow diagram of St. Rose Filtration Plant

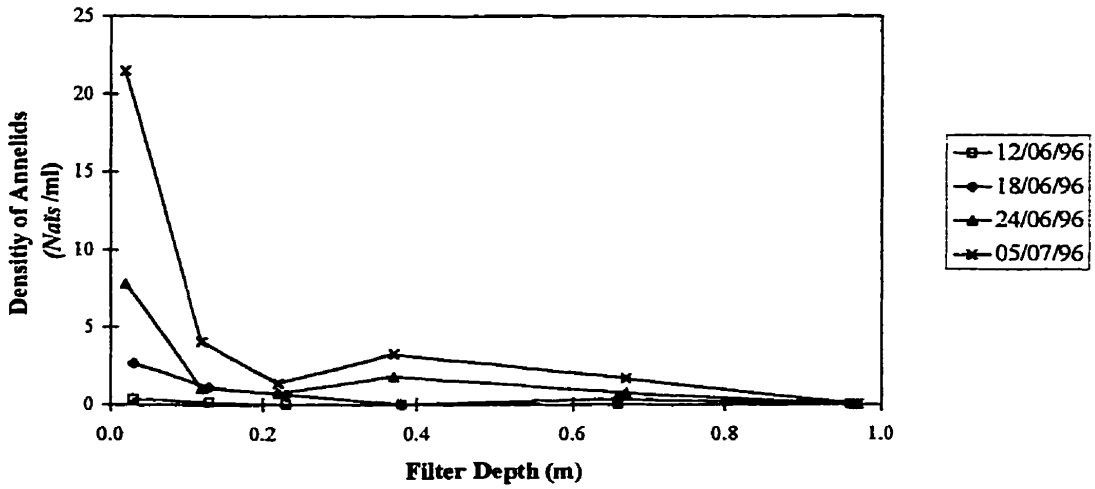

Figure 2 Monitoring density profiles of annelids in a BAC filter between June 12, 1996 and July 5, 1996

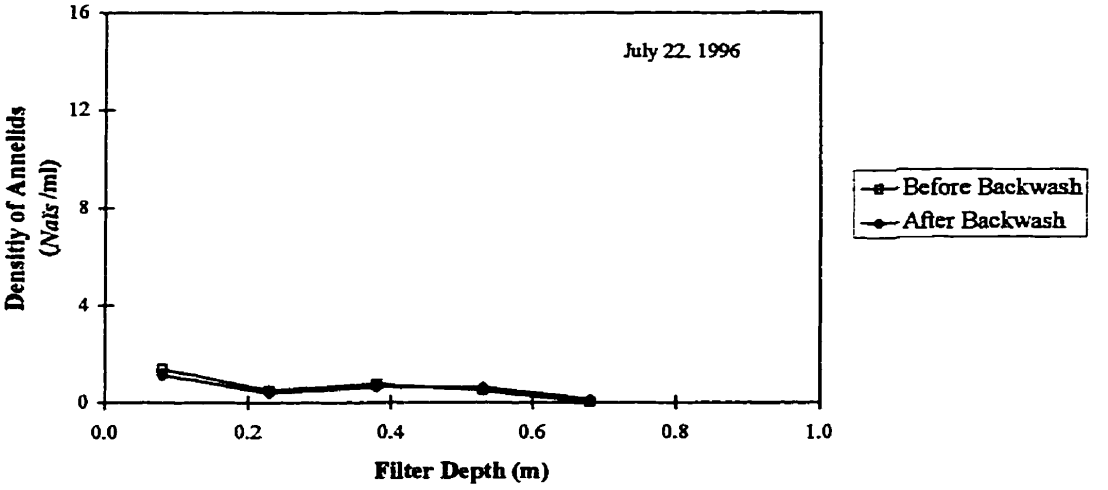

Figure 3 Impact of backwashing with water only at a medium flow rate (#1) on densities of annelids

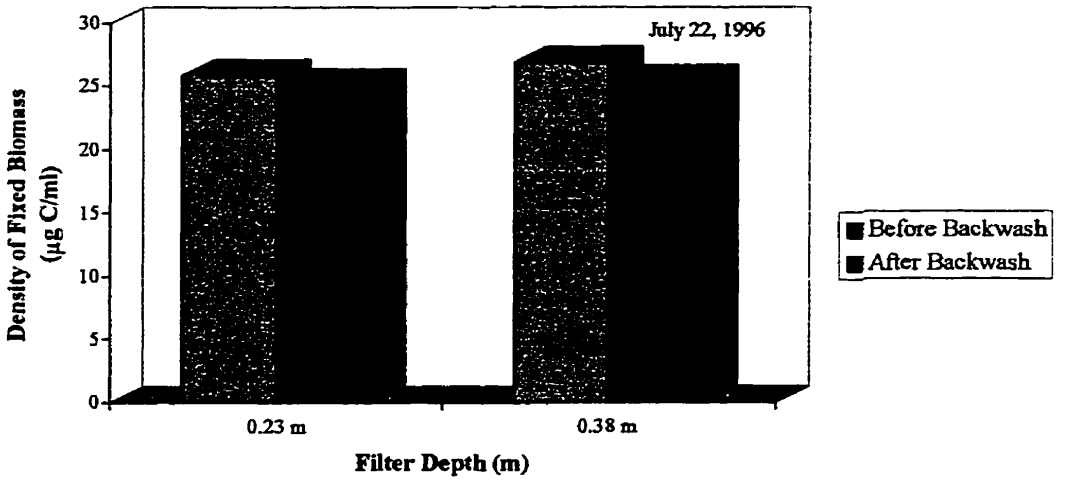

Figure 4 Impact of backwashing with water only at a medium flow rate (#1) on densities of fixed biomass

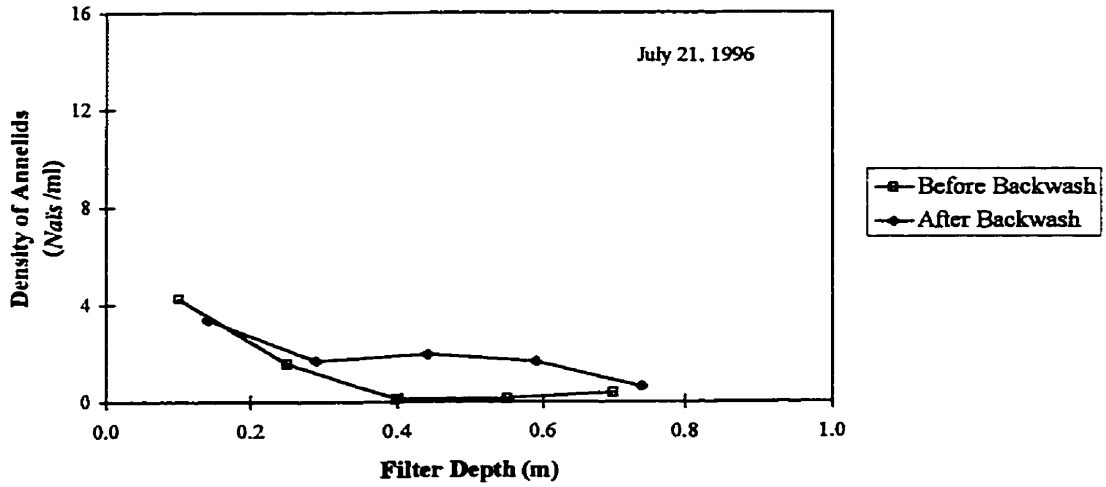

Figure 5 Impact of air scour followed by backwashing with water at a variable flow rate (#2) on densities of annelids

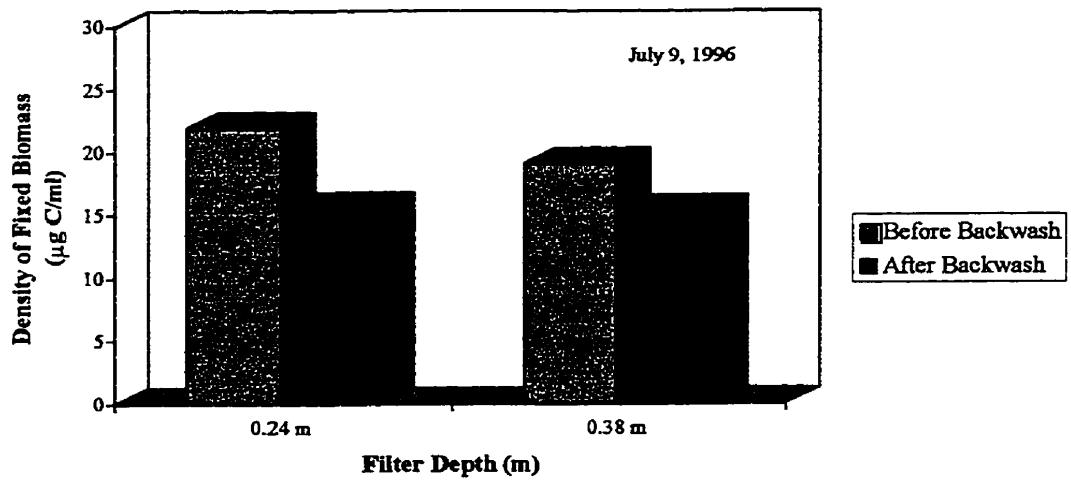

Figure 6 Impact of air scour followed by backwashing with water at a variable flow rate (#2) on densities of fixed biomass

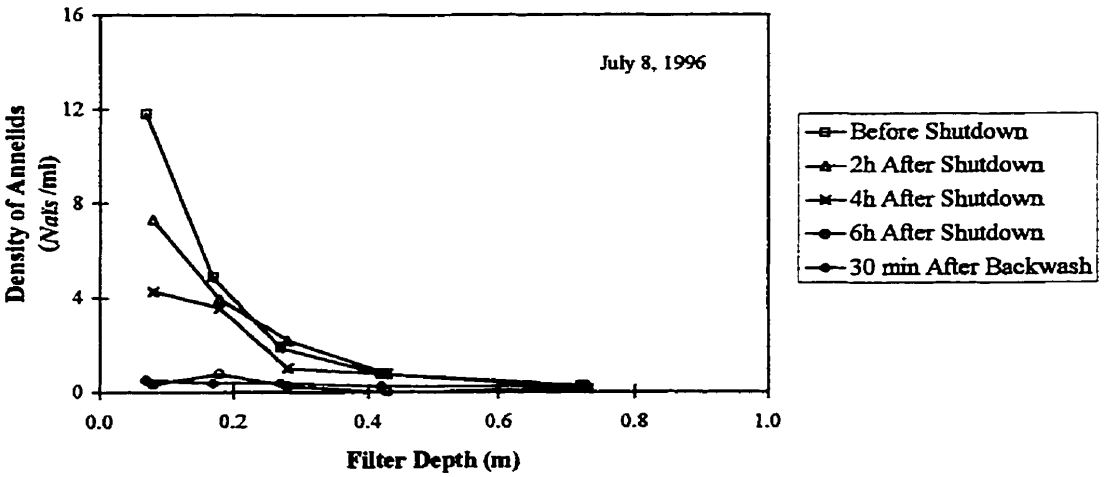

Figure 7 Impact of filter shutdown followed by backwashing with water at a low flow rate, air scour followed by backwashing with water at a medium flow rate (#3) on densities of annelids

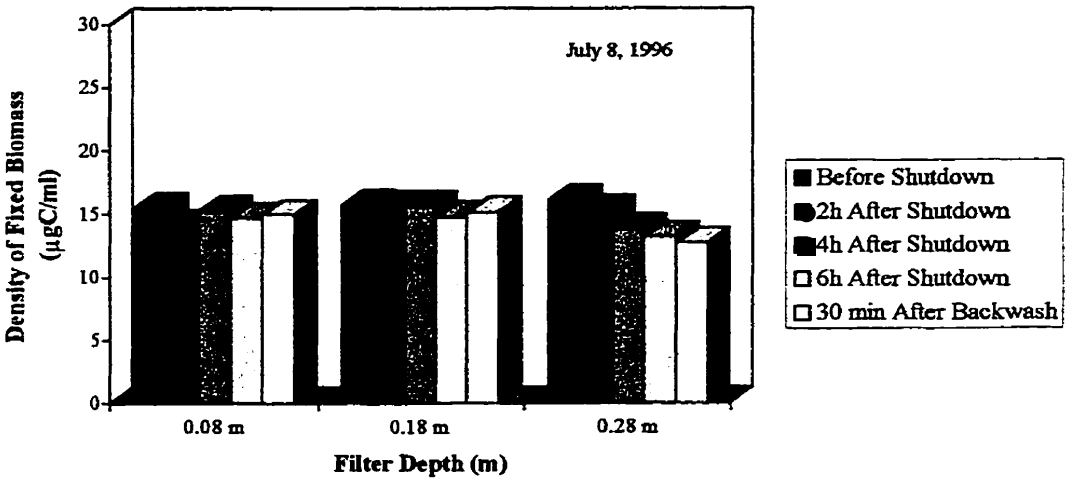

Figure 8 Impact of filter shutdown followed by backwashing with water at a low flow rate, air scour followed by backwashing with water at a medium flow rate (#3) on densities of fixed biomass

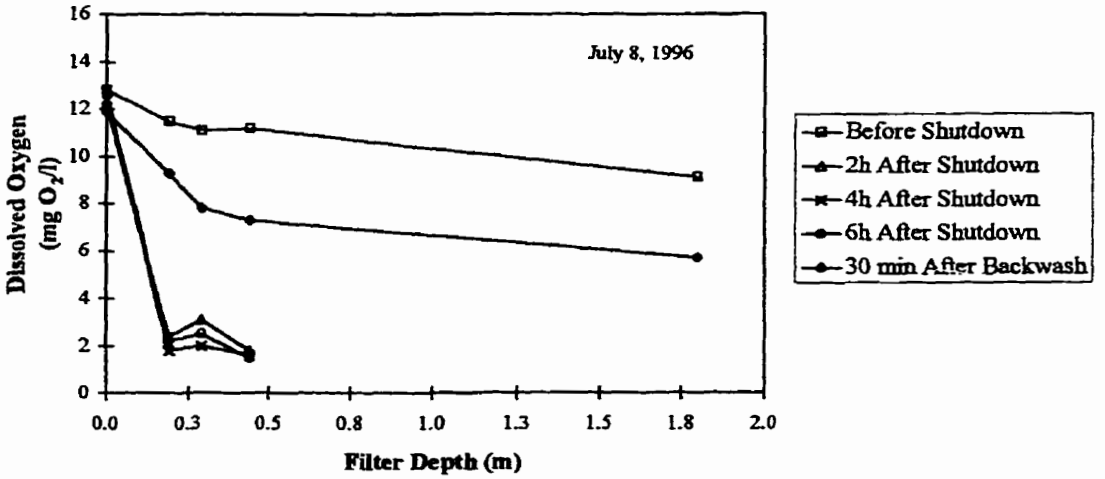

Figure 9 Impact of filter shutdown followed by backwashing with water at a low flow rate, air scour followed by backwashing with water at a medium flow rate (#3) on concentration of dissolved oxygen